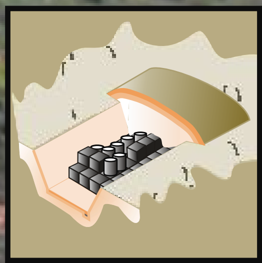
COMMONWEALTH DEPARTMENT OF EDUCATION SCIENCE & TRAINING

NATIONAL RADIOACTIVE WASTE REPOSITORY DRAFT EIS

APPENDICES





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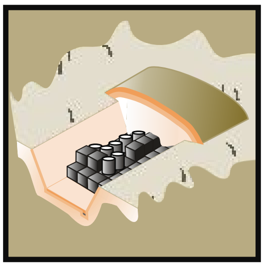

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VOLUME 2

ISBN 1877032085 (Set)

This environmental impact statement (EIS) has been prepared by PPK Environment & Infrastructure (PPK) on behalf of Department of Education, Science & Training (the Client). In preparing this EIS, PPK has relied upon and presumed accurate certain information provided by the Client, specialist subconsultants, certain State and Commonwealth government agencies and others identified herein. No warranty or guarantee, whether expressed or implied, is made with respect to the information reported or to the findings, observations or conclusions expressed in this EIS. Such information, findings, observations and conclusions are based solely on information in existence at the time of the investigation.

Printed by Five Star Press, Adelaide

Volume 2

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APPENDIX A

Appendix A

EIS GUIDELINES

Environment Australia

Department of the Environment and Heritage

A

Appendix A
Guidelines

Guidelines for an environmental impact statement on the proposed national low level radioactive waste repository — June 2001, reference 2001/151 issued by Environment Australia.

A.1 Preamble

The Commonwealth Department of Industry, Science and Resources proposes to establish a national repository for the disposal of Australia's low level and short-lived intermediate level radioactive waste resulting from the medical, research and industrial use of radioactive materials.

A region in the central-north of South Australia has been identified as the most suitable location for the proposed repository. One of three sites in this region is preferred on the basis of current knowledge but three sites will be examined in full in the environmental impact statement (EIS) that the Minister for the Environment and Heritage has directed be produced.

The proposed national low level radioactive waste repository would only accept low level and short-lived intermediate level waste (the EIS will clearly define these terms – see Section A.4 of these Guidelines). The national low level radioactive waste repository is not associated with the proposed storage facility for long-lived intermediate level radioactive waste generated by Commonwealth agencies. A separate search process to identify a preferred location for this intermediate level above ground store was announced by the Minister for Industry, Sciences and Resources in August 2000. The Government has made it clear that the intermediate level waste storage facility would be built on Commonwealth land and would not be co-located with the national low level radioactive waste repository.

The proposal to construct a national low level radioactive waste repository was referred to the Minister for Environment and Heritage for consideration as to whether or not approval was required in terms of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The objectives of the EPBC Act are provided at Attachment A. In short the EPBC Act provides for the protection of the environment, and one means of meeting this objective is to require that actions that will, or are likely to have, a significant impact on the environment are not taken without the approval of the Minister for the Environment and Heritage. Such an approval is not given without an environmental impact assessment having been carried out and the outcomes taken into account.

The Minister on 8 February 2001, determined that approval was required for the proposed national low level radioactive waste repository. The controlling provisions for the action under the EPBC Act are:

- Sections 18 and 18 A (Listed threatened species and communities)
- Sections 21 and 22 A (Protection of the environment from nuclear actions)
- Section 28 (Protection of the environment from Commonwealth actions).

Following the provision of preliminary information from the Commonwealth Department of Industry, Science and Resources, and advice from Environment Australia, the Minister determined on 2 March 2001 that the proposed establishment of the repository must be assessed (in terms of potential environmental impacts) by way of the preparation of an EIS.

This document provides guidelines (terms of reference) for the drafting of the EIS based on the formal requirements for the contents of a EIS provided in S97 of the EPBC Act and Schedule 4 of the EPBC Act Regulations 2000.

The draft EIS prepared by the Proponent must be approved for publication by the Minister prior to it being published in accordance with the regulations. An invitation for anyone to give the proponent comments relating to the draft report within the period specified must also be published. After the period for comment, the proponent must take into account comments received in finalising the EIS, which is then provided to the Minister. If the Minister accepts the final EIS, an assessment report is prepared by the Department of the Environment and Heritage. Following this, in accordance with Part 9, Division 1 of the EPBC Act, the Minister will decide whether or not to approve the proposal and attach any conditions required.

A.1.1 The Objectives of the EIS

Environmental impact assessment depends on defining adequately those elements of the environment that may be affected by a proposed development, and on identifying the significance, risks and consequences of the potential impacts of the proposal at a local, regional and national level. In this case the EIS will be the primary source of facts on which an assessment of the environmental impacts of the exploration proposal will be based by the public and government decision makers.

As the activity is a nuclear action and an activity of a Commonwealth agency, the matter protected and therefore requiring consideration in the assessment and approval process, is the environment. Section 528 of the EPBC Act defines “environment” as:

(a) ecosystems and their constituent parts, including people and communities; and
(b) natural and physical resources; and
(c) qualities and characteristics of locations, places and areas; and
(d) the social, economic and cultural aspects of a thing mentioned in paragraph (a), (b), or (c).

It is the responsibility of the proponent preparing the EIS to identify and address, as fully as possible, the matters relevant to the specific development proposal in complying with the statutory requirements for EIS preparation.

The proponent is to determine those parties who should be consulted during the preparation stage of the EIS. It is recommended that an open community consultation process be carried out, in addition to the legislated environmental impact assessment process. The requirements of Schedule 4 of Regulation 5.04 under the EPBC Act should be noted, particularly in relation to consultation with all affected parties (see Attachment D).

The EIS should provide a description of the existing environment in the area and the proposed operations involved in the activity. It should evaluate the environmental impacts and proposed measures to avoid or minimise the expected or likely impacts. Particular attention should also be paid to potential impacts on listed threatened species and communities and listed migratory species under the EPBC Act.

It is expected that additional ecological survey and other fieldwork will have to be undertaken to provide sufficient information for the EIS. The nature and level of investigations should be related to the likely extent and gravity of impacts. All potentially significant impacts of the proposal on the environment are to be investigated and analysed, and commitments to mitigate any adverse impacts are to be detailed in the EIS. Any feasible alternatives should be discussed in detail and the reasons for selection of the preferred action should be clearly given.

Completion of the EIS according to these guidelines does not mean that approval will necessarily be granted.

A.1.2 General Advice

The EIS should be a stand alone document. It should contain sufficient information from any studies or investigations undertaken to avoid the need to search out previous or supplementary reports.

The EIS should enable interested stakeholders and the assessing agency to understand the environmental consequences of the proposed development. Information provided in the EIS should be objective, clear, succinct and, where appropriate, be supported by maps, plans, diagrams or other descriptive detail. The body of the EIS is to be written in a clear and concise style that is easily understood by the general reader. Technical jargon should be avoided wherever possible and a full glossary included. Cross referencing should be used to avoid unnecessary duplication of text.

Detailed technical information, studies or investigations necessary to support the main text should be included as appendices issues with the EIS. Any additional supporting documentation and studies, reports or literature not normally available to the public from which information has been extracted should be made available at appropriate locations during the period of public display of the EIS.

If there is a necessity to make use of material that is considered to be of a confidential nature, for instance information obtained in regard to traditional use or of a commercial nature, the proponent may request that such information remain confidential and not be included in any publicly available document.

The EIS should state the criteria adopted in assessing the proposal and its impacts, such as: compliance with relevant legislation, policies and standards; community acceptance; maximisation of environmental benefits (if any); and minimisation of risks and harm.

The level of analysis and detail in the EIS should reflect the level of significance of the expected impacts on the environment. Priority should be given to the major issues associated with the proposal and matters of lesser concern should be dealt with only to the extent required to demonstrate that they have been considered. Any and all unknown variables or assumptions made in the assessment must be clearly stated and discussed. The extent to which the limitations, if any, of available information may influence the conclusions of the environmental assessment should be discussed.

A.1.3 Format and Style

The EIS should comprise three elements:

- the executive summary
- the main text of the document, which should be written in a clear and concise manner so as to be readily understood by general readers
- appendices containing detailed technical information or other sensitive commercial or cultural information.

These guidelines detail the required content of the EIS. This information has been set out in a manner which may be adopted as the format for the EIS. This format need not be followed where the required information can be more effectively presented in an alternative way. However, each of the elements must be addressed to meet the requirements of the EPBC Act and Regulations. The EIS should be written so that any conclusions reached can be independently assessed. To this end all sources must be appropriately referenced using the Harvard standard.

The main text of the EIS should include a list of abbreviations, a glossary of terms and appendices containing:

- a copy of these guidelines
- a list of persons and agencies consulted during the EIS
- contact details for the referral agency
- the names of, and work done by the persons involved in preparing the EIS.

Maps, diagrams and other illustrative material should be included in the EIS. The EIS should be produced on A4 size paper capable of being photocopied, with maps and diagrams on A4 or A3 size.

A.1.4 Detailed Requirements

Schedule 4 of the EPBC Act Regulations 2000 sets out the matters that must be addressed in an EIS. These are provided at Attachment D to these guidelines. The following requirements are based on these requirements with the addition of advice on presentation and consultation details that we have found to be valuable in communicating with members of the public and specific interest groups; and additional directions specific to the environment of the area of the proposal.

These guidelines are not necessarily exhaustive and should not be interpreted as excluding from consideration matters deemed to be significant, but not incorporated in them, or matters (currently unforseen) that emerge as important from environmental studies or otherwise during the course of preparation of the EIS.

A.2 Public Review Process

In preparing an EIS, the proponent should bear in mind the following aims of the EIS and the public review process:

- to provide a source of information from which interested individuals and groups may gain an understanding of the proposed action, the alternatives, the environment which it would affect, the impacts that may occur, and the measures to be taken to minimise those impacts
- to provide a forum for public consultation and informed comment on the proposal
- to provide a framework within which decision-makers may consider the environmental aspects of the proposed action and any measures for the protection of the environment.

The proponent should ensure that the EIS demonstrates compliance with principles of Ecologically Sustainable Development (ESD) as set out in the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)*, and the objectives of the Act (see Attachment A).

Section 1.6

The proponent should also comply with Schedule 4 of the *EPBC Regulations 2000* “Matters to be addressed by draft public environment report and environmental impact statement” (see Attachment D).

A.2.1 Certificate of Compliance and Invitation to Comment

A Certificate of Compliance and an invitation to provide comments should be placed at the beginning of the EIS. The Certificate of Compliance is a statement by the authors that the assessment document is in accordance with the guidelines prepared by, or on behalf of, the Minister. It also a states that the content is true in all material particulars and does not, by its presentation or omission of information, materially mislead. A proforma example is at Attachment C.

The Invitation for Comment is required under Section 103 of the EPBC Act and provides guidelines for parties interested in providing comment on the document to the proponent. An example of an Invitation for Comment will be supplied to the proponent with the final Guidelines.

A.3 EIS Content

The EIS should give priority to the major issues associated with the proposal. It is envisaged that the EIS will be based on the results of available research, studies and data as appropriate, with further studies being conducted where necessary and practicable. The extent to which the limitations, if any, of available information may influence the conclusions of the environmental assessment should be discussed.

The main text of the EIS should be written in a clear, concise style that is easily understood by the general reader. Technical jargon should be avoided wherever possible, otherwise technical terms should be defined in a Glossary of Terms. Detailed technical information, including drawings and studies, necessary to support the main text should be included as Appendices attached to the EIS.

The documentation EIS should include references and a list of individuals and organisations consulted and the nature of the consultation undertaken. Clear maps and illustrations should also be included to assist the public in understanding the proposal and its impacts.

Main Report (reference list)
Appendix G

A.3.1 Summary

The EIS must include a summary of the matters discussed in the main body of the document, to allow the reader to quickly obtain a clear understanding of the proposal and its environmental implications. It may include:

- the title of the proposal and location
- name and address of the proponent
- a brief discussion of the background to, and need for, the proposal
- a brief description of the proposal
- identification of the National Environmental Significance (NES) criteria relevant to the action
- a brief description of the existing environment pertaining to the relevant NES criteria
- a description of the principal environmental impacts, particularly impacts on relevant NES criteria
- a brief description of issues associated with the surveillance phase and eventual decommissioning
- a statement of the monitoring and environmental protection measures proposed or required.

A.3.2 Introduction

The introduction should include a clear definition of the objectives of the proposal. A brief explanation of the purpose, scope and legislative basis for the EIS should be provided, including the role of the EIS in the government's decision-making process, and the status of any related state/local Government assessments.

Section 1.1
Section 1.2

The study area and regional setting for the proposal, including land use, tenure and potential for application of the Native Title Act 1993 should be described. Clear maps should be provided as appropriate. The location of the action requiring approval must be indicated.

Section 1.4
Figure 1.1

The introduction should also describe the studies/surveys/consultations that have been conducted in developing the proposal and preparing the EIS. The structure of the document should be briefly explained.

Section 1.5
Section 1.3

Consultation with Commonwealth and state agencies, in particular agencies responsible for existing land use, local government and the community undertaken in developing the proposal and EIS should also be summarised in the appendices along with comments as a result of the consultations.

Section 1.5.3
Appendix G

The specific NES criteria potentially affected by the action, and specific approvals needed under the EPBC Act, must be stated.

Section 1.2

A.3.3 Background

The EIS should discuss the background to the proposal, covering, for example:

- Authority **/**Legislative basis for the proposal — Section 3.2, 3.3
- Legislative basis for management of nuclear wastes
- Legislation which applies to the use of the waste materials which comprise the matrices in which nuclear waste is contained
- general information on responsibilities and relationships between Commonwealth and State regulatory agencies on nuclear matters, as relevant to the proposal
- general information on responsibilities and relationships between Commonwealth and State regulatory agencies on environmental matters, as relevant to the proposal
- consistency of proposal with Australia's non-proliferation and related safeguards obligations.
- chronology of site determination, including rationale for adopting preferred sites. — Section 5.1, 5.2

A.3.4 Reviews Relevant to the Proposal

Recommendations and conclusions of reviews relevant to the proposal eg:

- Australia's Role in the Nuclear Fuel Cycle, ASTEC, 1984
- Senate Select Committee, Research Reactor Review *Future Reaction*, August 1993
- Senate Select Committee, Dangers of Radioactive Waste, *No Time to Waste*, April 1996
- Committee *on Uranium Mining and Milling*, May 1998 — Section 2.6
- Ministerial recommendations on Replacement Nuclear Research Reactor at Lucas Heights, March 1999, Parliamentary Standing Committee on Public Works *Replacement Nuclear Research Reactor, Lucas Heights, NSW*, August 1999, and
- Senate Economics References Committee *A New Reactor at Lucas Heights*, September 1999,
- Relevant international conventions relating to transport, storage, and disposal of radioactive waste. — Section 3.1

A.3.5 Need for the Proposal

Provide an explanation of the need and justification for the proposed action including:

- need for the proposed action arising from any relevant planning or policy framework — Section 1.6
- expected community, regional, state or national benefits
- other expected benefits
- implications of not establishing the repository.

A.3.6 Alternatives to the Proposal

The EIS should describe any feasible alternatives to the proposed action, including the 'no project' alternative, alternative locations and alternative technologies.

- The document should focus on alternatives with the potential to minimise impacts on the identified NES criteria. Short, medium and long term advantages and disadvantages of the options should also be considered, including the likelihood of any extension of the proposed life of the facility. — Section 1.7

▪ Alternatives should be discussed in sufficient detail to make clear the reasons for preferring certain options and rejecting others.	Section 1.7
▪ The reasons for choice of the preferred option should be explained, including a comparison of the adverse and beneficial effects used as the basis for selection, and compliance with the objectives of the EPBC Act and ESD principles.	Section 1.6
▪ Overseas strategies and current best practice for dealing with low level radioactive waste should be discussed in detail (see also Section 5.5).	Sections 2.5, 5.3

A.3.7 Existing Waste Management — Overseas and in Australia

▪ Outline the various types of waste repositories, and the distinction between disposal requirements for different types of nuclear wastes.	Section 2.3
▪ Description of current waste storage and management regime in Australia, including production, storage, conditioning and transport, for example, repositories at Mount Walton East, WA and Esk in Queensland should be discussed, including any impacts on the environment from those operations.	Section 2.4
▪ General information should be given on waste repository sites and sites with a similar function to that proposed in Australia, in operation throughout the world, their use and classification, size range, age, characteristics, **performance** and safety and regulatory arrangements. A conclusion should be drawn as to current best practice in this field and its relevance to the Australian experience.	Section 2.5

A.4 Radioactive Waste to be Held in the Repository

A.4.1 Type of Radioactive Waste to be Held at the Repository

This section should include:

▪ Clear definitions of low and intermediate level radioactive waste. The origin of the definitions used and their status in terms of acceptance by regulatory and advisory bodies (national and international) should be identified.	Sections 2.3, 3.2
▪ Estimates of the existing inventory of low level and short-lived intermediate level radioactive waste by types, activity, decay periods, homogeneity and volumes suitable for disposal in the repository.	Section 4.1

A.4.2 Amount of Radioactive Waste to be Held at the Repository

This section should include:

▪ The expected annual generation of low level and short lived intermediate level wastes.	Section 4.2
▪ Waste arisings from the decommissioning of nuclear plant, such as will exist at the Hi-Flux Australian Reactor (HIFAR) at Lucas Heights.	
▪ Estimates of future arisings of low level category wastes that may need disposal within the operational lifetime of the facility.	
▪ The ultimate capacity of the repository by type, activity, decay periods, homogeneity and volume of waste.	
▪ Minimum requirements for waste characterisation, for example radionuclide activity, the matrix (inert materials used to surround the radioactive waste) to be employed and related matters.	Section 4.3

A.5 Description of the Repository Facility

A.5.1 Description of Site Selection Process

The following issues should be addressed:

▪ Detailed siting requirements, including the NHMRC Code of Practice for the near-surface disposal of radioactive waste in Australia.	Section 5.1
▪ Siting requirements of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) as well as other national and international criteria that may be relevant, including environmental, engineering and contaminant transport legislation and guidelines.	Sections 5.1, 5.3
▪ Site Selection Study for a Radioactive Waste Repository for Australia, including background, methodology, community consultations leading to preferred site(s).	Section 5.2
▪ Siting in the context of strategic planning in South Australia, including state and local government planning and policy controls.	Section 10.2, 10.5
▪ Characteristics of the preferred site and whether or not the chosen site meets the above selection criteria.	Table 5.2, Section 5.2
▪ Alternative locations identified in the Site Selection Studies.	Figure 1.3

A.5.2 Description of the Repository

All components of the proposal, should be described in detail, including:

▪ Area of the facility, covering buffer zone, repository, and buildings.	Section 6.1–6.2, 6.3 Figures 6.2, 6.3, 6.4, 6.5
▪ The specific locations and elevations of associated trenches, buildings, accommodation, fences and other infrastructure.	
▪ Full description of all engineering/mechanical defences and estimated effectiveness over the life of the site.	Section 6.2, 6.6–6.9
▪ Technical information should be supported by maps, figures and diagrams. Any detailed technical information should be included in the appendices.	
▪ Other infrastructure requirements, including weather protection, roads and car parking, water (including water and waste water services and drainage), electricity, gas and telecommunications.	
▪ General description of the main phases of the repository project, including ARPANSA licensing processes at each stage, (construction, operation, surveillance period and decommissioning).	Sections 6.4, 6.5, 6.8, 6.9, 3.3

A.5.3 Description of Construction Works

The following matters should be discussed:

▪ Process and timetable for tender, selection and construction of the proposed repository.	Section 3.3, 6.10
▪ Timing of work program, duration of construction phase, including lead times.	Section 6.4
▪ Nature of the work, machinery that will be required.	
▪ Size of construction workforce.	
▪ Accommodation requirements.	
▪ Site access arrangements.	Section 7.4
▪ Extent of earthmoving, building demolition/relocation, vegetation clearance and other site preparatory works, including arrangements to minimise unnecessary clearance and disturbance.	Section 6.4, 9.4

▪ Proposed engineering designs and technologies to address geological, seismic, hydrogeological, climatic and other characteristics of the site.	Section 6.4
▪ Performance specifications for the repository and tender requirements for example design philosophy, type of disposal structures, configuration.	Section 5.3
▪ Construction standards, techniques and site management arrangements, including on-site storage and handling of construction and other materials including fuel, oil.	Sections 6.3, 6.4
▪ The design parameters for those aspects with potential impacts on NES criteria described in detail.	Section 5.3
▪ Arrangements for disposal of construction wastes during and following construction.	Section 6.4
▪ Arrangements for erosion control and rehabilitation of construction site(s), both during and following construction.	Sections 8.10, 8.11
▪ Description of any special commissioning procedures and requirements, including ARPANSA requirements for licensing construction.	Sections 3.3, 6.4

A.5.4 Description of Operations at the Repository

The following matters should be covered:

▪ General description of activities to occur at the facility.	Section 6.5
▪ Detailed description of expected operations, timing, specific activities, including on-going trench construction, radioactive waste burial, and trench closure.	Sections 6.1, 6.2, 6.5
▪ Type of activities in the buffer zone.	Section 6.1
▪ Water, waste water and sewage management, including arrangements to minimise water and energy use.	Section 6.3
▪ Storage and transport arrangements for hazardous fuels and chemicals.	
▪ Operational workforce, composition of workforce and any infrastructure requirements, including accommodation.	Section 6.5
▪ Occupational health and safety arrangements, including health physics procedures for workers and visitors.	Section 6.6
▪ Procedures for the protection of community health and safety.	
▪ Security and surveillance arrangements.	
▪ Environmental monitoring arrangements including radiation monitoring of air, soil, flora, fauna, surface and ground water.	Section 6.6, 13.2

A.5.5 Description of Disposal Methods, including Encapsulation and Packaging of Waste

The EIS should define what will be suitable to go into the repository, in terms of concentration limits for various radionuclides and the sort of packaging which will be required for various materials. The guidelines concerning what could be accepted for near-surface or above ground disposal, should be adapted for the particular site and circumstances. World's best practice in this area should be identified, referenced and outlined. (Section 4.3, 3.1, 3.2)

If other hazardous materials, such as chemical compounds are mixed with the radioactive waste, criteria will need to be established to determine what is acceptable, and the options discussed in the EIS. Details of expected hazardous materials are to be provided in the EIS. Bi-products and any changes in the state of the waste should be identified, along with the environmental implications. (Section 4.3)

The discussion of waste protection, including encapsulation of wastes, natural protection offered by site characteristics and engineered barriers, should include the following:

- Proposed waste packaging for example, metal drums, concreted drums and concreted boxes. — Section 4.3
- Proposed encapsulation of waste, acceptance criteria, conditioning requirements and practices.
- Testing and strength of proposed packaging.
- Facilities needed for characterisation, compaction, conditioning and encapsulation of wastes (at the facility or elsewhere).
- Requirements for on-site quality control: — Section 4.3, 6.7
  - *Provision* for wastes received for disposal, but not meeting the facility acceptance criteria (for example inappropriately packaged waste including poorly packaged or damaged waste packages, the inclusion of materials not suitable for disposal in a near-surface facility).
  - *Verification* or repair of faulty packaging.
  - *Possible* requirement for an on-site shielded radioactive waste handling facility.
- Proposed disposal/ storage procedures including burial and alternative approaches. — Section 6.3
- Protection to be provided during the surveillance phase - soil, bituminous membranes, concrete, gravel matrix. — Section 6.8
- Alternative disposal methods and technologies including below and above ground. — Section 1.7
- Description of methods and reasons for selection of preferred methods and technologies (including examples of world's best practice and discussion of efficiency, cost, safety, environmental and other criteria), see also Section A3.6. — Section 2.5, 5.3

A.5.6 Recording and Retrieval of Disposed Wastes

- Management prescriptions/protocols to ensure adequate institutional control of the facility and disposed wastes for the operational and surveillance life of the facility, including redundant systems for collection and storage of data concerning disposed wastes. — Section 6.7
- Recording locations of waste packages.
- Options for retrieval of waste under different disposal methods and scenarios (see also Section A3.6).

A.5.7 Description of Surveillance Period

The proposed means of surveillance should be described including:

- Expected activities during the surveillance phase, including land use and access restrictions. — Sections 6.8, 13.2
- Arrangements for monitoring air, soil, flora and fauna, surface and ground water.
- Security and surveillance arrangements.

A.5.8 Description of Decommissioning Phase

Any further studies that may be required prior to determining the final strategy for decommissioning should be described. Information should be provided on the following:

- Decommissioning activities, including likely timings and estimated costs. — Section 6.9
- Disposal of infrastructure and plant, including decontamination.
- Rehabilitation of the site and any other affected areas.

▪ Options and strategies for decommissioning, including any staged approaches, design considerations, likely timings and constraints that may influence the type and extent of decommissioning.	Section 6.9
▪ ARPANSA requirements for licensing decommissioning.	
▪ Arrangements for any on-going monitoring beyond the decommissioning phase.	Section 13.2
▪ A description of waste remaining at the site after decommissioning.	Sections 6.9, 4.1, 4.2

A.6 Transport of Waste to the Repository

A.6.1 Regulatory Regime

Details of state, national and international regulatory regime including:

▪ NHMRC Code of Practice for the transport of radioactive waste and any subsequent Codes.	Section 3.2
▪ IAEA Code of Practice for the transport of radioactive substances.	
▪ Transport regulations which cover any dangerous goods that may form matrices around the radionuclides.	

A.6.2 Proposed Transport Routes

The following aspects of proposed transport routes should be addressed:

▪ Likely transport routes on public and private roads.	Section 7.2, Fig 7.1 Section 7.4, Fig 7.2
▪ Input from the communities located along the proposed transport routes to determine the acceptance and perception of the risk associated with transport activities.	Section 5.5
▪ Significant cultural and environmental areas along transport corridors.	Sections 9.2, 11.1

A.6.3 Transport Safety

Details of proposed safety arrangements including:

▪ The relative likelihood for an accident or incident to occur.	Section 7.6
▪ The ability of emergency service organisations to cope with any incidents that occur along transport routes including response times for areas remote from cities and towns and the training of the personnel and suitability of equipment of these organisations.	
▪ A description of the emergency clean up and rehabilitation programs to be in place.	
▪ The frequency of international accidents and incidents and the corresponding impacts on the natural and human environment.	
▪ The likelihood of incidental exposure to the natural and human environment as a result of accident, fire, sabotage and natural catastrophic events during transport of wastes.	
▪ The suitability of containers and their ability to survive high velocity impacts and high temperatures.	Sections 7.2, 7.6, 14.5

A.6.4 Transport Options

Details of transport options are to include:

▪ Alternative transportation methods including possible road, air, sea and rail.	Section 7.3
▪ Expected frequency of transport of waste to the repository.	Section 7.2,
▪ Methods of transport in terms of ESD including the precautionary principal.	Table 7.1
▪ Possible treatment of wastes at existing holding sites.	Section 7.3, 4.3 Table 7.2

A.7 Description of Existing Environment

A description of the present physical, biological and socio-economic environments in the study area should be provided. It should include:

- Sufficient detail to allow a clear understanding of the likely impacts of the proposal, and to assess the effectiveness of any proposed mitigation measures, against NES criteria.
- Methodologies used to describe the existing environment (i.e. mapping, survey and groundwater monitoring techniques) and to determine or predict impacts on the environment.
- Justification on the ability of the chosen methodologies to fully and accurately describe the environment and any impacts which may occur.
- A study area sufficiently large to include any possible impacts from the proposal, for example along transport corridors and areas likely to receive ground water from the proposed repository site.

A.7.1 Description of Physical and Biological Environments

This should include:

▪ Geology, geomorphology, seismic stability, soil types and permeability.	Section 8.1, 8.2
▪ Topography.	Appendices C1–C3
▪ Hydrology (surface and ground water).	
▪ Detailed geochemical baseline data should be supplied for all bores in the groundwater monitoring regime	
▪ Radiological assessment (including background dose rates, concentrations of radionuclides in air, water and soil).	Section 12.1
▪ Meteorology of the sites, including extreme events that may be relevant to safety aspects of the proposal.	Section 8.6, 12.9
▪ Existing air and water quality.	Section 8.7, 8.5
▪ Incidence of bushfires.	Section 8.9
▪ Past, present and potential future use of the sites.	Section 10.4, 10.6
▪ Flora and fauna, presence of species of local, regional or state significance including those under the EPBC Act (1999) potentially affected by the proposal.	Sections 9.2, 9.3
▪ Key food chains and ecological interactions (particularly relevant to potential radiological pathways).	Section 12.2
▪ Conservation significance of the site, buffer zone and region, including proximity to National Parks, wilderness areas, wetland areas, locally and nationally significant species, and habitats used by species listed under CAMBA and JAMBA.	Section 9.2, 9.3

A.7.2 Description of Socio-economic Environment (including trends over the expected life of the repository)

Issues that should be covered include:

▪ Ownership of the sites and adjoining areas.	Section 11.2
▪ Zoning, land uses, local government planning.	Section 10.2, 10.4
▪ Possible future zoning, planning controls, changes in land use, and nearby developments.	Section 10.5, 10.6
▪ Proximity to areas routinely used by people.	Section 10.4
▪ Proximity to hazardous or other potentially incompatible land uses.	
▪ Proximity to airports and flight routes.	Section 10.5
▪ Demographic characteristics of nearby communities.	Section 10.4
▪ Future population growth.	Section 10.6
▪ Employment levels and characteristics.	Sections 10.4, 10.6
▪ Wider community views and attitudes towards the proposal.	Section 1.5.
▪ Road/rail access, traffic flow and capacity.	Sections 7.3, 7.4,
▪ Other infrastructure as relevant.	10.7
▪ Recreational use of surrounding areas.	Section 10.6.3
▪ Landscape/visual environment.	Section 10.3, 10.7
▪ Sites listed on the Register of the National Estate and sites of European historical significance.	Section 10.7 Section 11.2
▪ Potential impacts on South Australian agriculture, tourism and other enterprises.	Section 10.6

One of the three sites to be subject to environment impact assessment in the EIS (Site 52A - Evetts Field West), falls within the boundaries of the Woomera Prohibited Area (WPA) in which the Department of Defence is a major stakeholder.

Without limiting in any way a comprehensive environment assessment of all three possible repository sites, the proponent is to consider the relationship of existing or likely future activities in the WPA with any proposed repository. Studies required in relation to the repository should include risk assessment of activities in the WPA. Potential impacts of all repository activities on existing land holders, including the Department of Defence are also to be assessed.	Sections 10.4, 10.7

A.7.3 Aboriginal Cultural and Heritage Significance and Identification with the Region and Sites

Issues that should be covered include:

▪ Aboriginal affiliations with the region.	Section 11.1
▪ Past, existing and future land uses, including the ability to generate income from those land uses.	Section 11.1, 11.2
▪ Sites of heritage or cultural significance.	Section 11.1
▪ Sites of archaeological significance.	
▪ Ownership of the land, land claims and community aspirations.	Section 11.1, 11.2
▪ Aboriginal views and aspirations towards the proposal.	Section 11.1

A.8 Impacts and Risks to Natural and Human Environments

The EIS should discuss the predicted environmental impacts expected to result from the proposal.

- Risks to the natural and human environments must be identified and discussed.
- Generally, the discussion should use the same indicators and descriptions used to describe the existing environment.
- The discussion must specifically address the NES criteria preferably in the context of ESD principles.

In addition:

- Significant change to the environment should be defined for all parameters.
- Detectable change to the environment should be quantified in terms of baseline and ongoing monitoring. Impact indicators should be identified.
- Baseline data should be supplied.

All risk assessment modelling needs to include; site specific data used, assumptions made, the limitations of the model and sensitivity analysis for all key input parameters.

Direct and indirect, short-term and long-term, temporary and permanent, adverse and beneficial effects should be described and, where possible, quantified.

- The reliability of forecasts and predictions should be indicated as appropriate, together with confidence limits as part of a risk assessment process. Underlying data should be accessible and assumptions used substantiated.
- The groups of people affected by impacts or those expressing particular concerns should be identified (demographic assessment) and the adverse and beneficial effects on each group described.
- Sufficient quantitative analysis should be provided to indicate whether risks from the proposal are likely to be acceptable when compared with similar overseas facilities and national and state standards/guidelines for other hazardous industries.

The discussion should also cover:

- International standards and relevant publications or studies concerning risks.
- International experience, including the location and safety record of similar facilities.
- Evolution in the safe management of low level radioactive wastes.
- Perceptions of risk from the repository, including wider community perceptions.

A.8.1 Environmental Impacts and Risks in Initial Construction Phase

The impacts of construction works associated with the proposal and infrastructure (including impacts from buildings, car parks and roads) on the environment should be described, including:

- Effects of dust, vibration and blasting.
- Effects on drainage lines, groundwater and water quality.
- Effects and extent of earthworks, including clearing of vegetation and potential soil erosion.
- Contamination assessment of soils to be excavated, if required.

Sections 13.2, 8.7–8.11, 9.4, 9.8, 10.7, 12.3

- Impacts on flora and fauna (including species under the EPBC Act 1999) and areas of conservation significance.
- Nature and extent of likely construction noise (including construction traffic).
- Impacts of construction activities and workforce on demographic characteristics, employment and economies at the local, regional and state level.
- Impacts on road networks, traffic and infrastructure.
- Transport of materials and disposal of construction wastes.
- Visual and aesthetic impacts of construction works, and of the completed facilities, from public roads and public vantage points.
- Rehabilitation and landscaping.

Sections 13.2, 7.2, 8.7–8.11, 9.4, 9.8, 10.7, 12.3

A.8.2 Environmental Impacts and Risks in the Operational Phase

The impacts of the operation of the facility, and associated infrastructure, should be described including:

- Impacts of ongoing construction of trenches and other works for waste disposal, requirements for concrete batching and other heavy machinery.
- Impacts of storage of hazardous fuels and chemicals.
- Impacts of permanent and temporary changes to drainage lines.
- Impacts of operations on air, soil, flora and fauna, surface and ground water and areas of conservation significance.
- Impacts on local communities of operational workforce, infrastructure requirements and support.
- Impacts on water requirements, waste water, storm water management and sewage treatment.
- Impacts for public or other uses of the proposed buffer zone and surrounding region.
- Impacts of night lighting and security.
- Impacts of operations on local road networks and traffic.
- Impacts of transport of radioactive waste to the repository on local regional, state and national road networks, including likely routes, mode of transport and expected frequency.
- Visual impacts of completed facilities, location and elevation of buildings, landscaping, visual appearance from public roads and other public vantage points.
- Wider community attitudes towards the proposal.

Sections 13.2, 7.6, 8.7–8.11, 9.5, 9.8, 10.7, 12.4, 12.5, 12.9, 12.10

Risks of contamination to the environment and the consequences need to be considered in detail, including:

- Incidents such as accidental spillages or releases.
- Risks of contamination of the air, soil, flora, fauna, surface and ground water.
- Other hazardous waste products.
- Threats to current and future land use - for example agriculture, tourism, defence and aerospace activities.
- External risks to the facility, including risks from seismic activity, extreme meteorological events, bushfires, air traffic, sabotage and nearby Department of Defence facilities such as use of Woomera Prohibited Area for testing of war materiel as well as space launch vehicles.
- Atmospheric emissions, including intentional and unintentional releases of radionuclides and a discussion of any releases in terms of anticipated volumes, dispersion, approved discharge limits and impacts.

Sections 13.2, 7.6, 8.7–8.11, 9.5, 9.8, 10.7, 12.4, 12.5, 12.9, 12.10

- Aqueous emissions, including intentional and unintentional releases directly to the environment and/or to the water management system, anticipated volumes, discharge limits, and anticipated impacts on surface/ground water and subsequent uses of this resource. — Sections 13.2, 7.6, 8.7–8.11, 9.5, 9.8, 10.7, 12.4, 12.5, 12.9, 12.10
- Cumulative risks to humans and the environment during the operational and surveillance phases of the project including: — Sections 12.2, 12.4, 12.5, 12.7
  - Analysis of exposure pathways to the environment and humans.
  - *Accumulation* through environmental pathways and the food chain.
  - Risks associated with characterisation, encapsulation, conditioning, quality assurance and certification of waste packages.
  - *Implications* of proposal for existing health status of any nearby communities, or surrounding land uses, review and assessment of health risks, background information on likely effects and levels of ionising radiation.
  - *Assessment* of overall environmental risks from all elements of the proposal.

A.8.3 Environmental Impacts and Risks in the Surveillance Phase

The discussion of the impacts of activities during the surveillance phase should include:

Sections 13.2, 8.7–8.11, 9.6, 9.8, 10.7, 12.2, 12.5, 12.7, 12.8, 12.9

- Impacts of staffing, infrastructure and other resource requirements.
- Impacts of security and maintenance, safety surveillance programs and monitoring.
- Impacts on air, soil, flora, fauna and surface and ground water.
- Impacts on flora and fauna and areas of conservation concern.
- Impacts on local road networks and traffic.
- Impacts on public or other uses of the proposed buffer zone and surrounding region.
- Risks from prospective changes in land uses and implications for the facility.

Risks of contamination to the environment and their consequences need to be considered in detail, including:

Sections 13.2.3, 8.7–8.11, 9.6, 9.8, 10.7, 12.2, 12.5, 12.7, 12.8, 12.9

- Risks of contamination of surface and ground water.
- Other hazardous waste products.
- External risks to the facility, including risks from seismic activity, extreme meteorological events, bushfires, air traffic, sabotage and nearby Department of Defence activities such as use of the Woomera Prohibited Area for testing.
- Atmospheric emissions, including intentional and unintentional releases of radionuclides and a discussion of any releases in terms of anticipated volumes, dispersion, approved discharge limits and impacts.
- Aqueous emissions, including intentional and unintentional releases directly to the environment and/or to the water management system, anticipated volumes, approved discharge limits, and anticipated impacts on surface/ground water and subsequent uses of this resource.
- Cumulative risks to humans and the environment during the operational and surveillance phases of the project including:
  - Analysis of exposure pathways to the environment and public.
  - *Accumulation* through environmental pathways and the food chain.
  - *Risks* associated with characterisation, encapsulation, conditioning, quality assurance and certification of waste packages.

- *Implications* of proposal for existing health status of any nearby communities, or surrounding land uses, review and assessment of health risks, background information on likely effects and levels of ionising radiation.
- *Assessment* of overall environmental risks from all elements of the proposal.

Sections 13.2, 8.7–8.11, 9.6, 9.8, 10.7, 12.2, 12.5, 12.7, 12.8, 12.9

A.8.4 Environmental Impacts and Risks of Decommissioning Phase

Issues associated with the eventual decommissioning of the facility must be discussed, including:

- impact of expected decommissioning activities
- impact of disposal of infrastructure and plant, including decontamination activities
- final use of the site and project area after decommissioning and any long-term implications in terms of future land uses
- risks from prospective changes in land uses and implications for the facility
- threats to current and future land use in the region for example agriculture, tourism and bush tucker.

Sections 13.2, 8.7–8.11, 9.7, 9.8, 10.7, 12.6, 12.8, 12.9

A.8.5 Impacts and Risks to Aboriginal Heritage and Community Aspirations

Impact on Aboriginal cultural and heritage values applicable to the site and region should be discussed in detail. The results of any studies and consultations should also be reported in the EIS, as relevant. Issues to be considered may include:

- Likely impacts of the various stages (construction, operation, surveillance and decommissioning) on Aboriginal culture and heritage values.
- Impact on sites of archaeological and cultural significance.
- Impacts on current or foreseen Aboriginal uses of land or other resources in the region.
- Impacts on Aboriginal aspirations, ownership and land claims in the region.
- Aboriginal views concerning the proposal.
- Opportunities associated with the proposal, (employment, monitoring).

Sections 11.1

A.9 Environmental Safeguards to Minimise Impacts and Risks to Natural and Human Environment

This section should describe all safeguards proposed to prevent or, in the event of unforeseen damage, rehabilitate the damaged environment.

- It should draw together all relevant information mentioned in the text together with a clear statement of specific commitments that the proponent will make.
- Any actions required by others to enable the proponent to meet these commitments should be identified (for example, oversight of monitoring, safeguards and environmental management).

Chapter 13

▪ A list of commitments must be contained in a separate section of the EIS and cross referenced to the text.	Chapter 13
▪ Measures to ensure regular audit and review of environmental commitments (and environmental management in general) must be described.	

A.9.1 Environmental Safeguards

Environmental management strategies proposed to mitigate adverse environmental impacts during construction, operation and surveillance should be identified.	
▪ This may be in the form of a draft environmental management plan (EMP).	Section 13.1
Proposed measures to ensure that the action is implemented and managed in an ecologically sustainable manner, and to minimise impacts on NES criteria, should cover:	
▪ The environmental management principles (including EMP) which would be followed in the planning, design, construction, operation and surveillance phases of the repository.	Section 13.1
▪ A description of mitigation measures, processes or procedures or changes to the proposal to prevent or minimise environmental impacts on relevant matters of NES, and information relating to conditions which may be placed on an approval of the proposal to address identified impacts on NES matters.	Sections 13.2
▪ Measures proposed or required by way of offset for any unavoidable impacts on NES criteria and the appropriate degree of compensation.	
Environmental safeguards to avoid and mitigate impacts on the environment to be discussed, should include the following:	
▪ Design, construction and operational requirements of the facility to satisfy relevant codes, standards, and radioactive activity and dose limits. ▪ Mechanisms for handling unexpected release incidents. ▪ Mitigation of construction impacts, including dust suppression, noise control, control of erosion and sedimentation, soil and water management plan, site rehabilitation and landscaping. ▪ Role and adequacy of the proposed buffer zone. ▪ Minimisation of waste, including waste avoidance, re-use and recycling. ▪ Minimisation of risks from facility operations, including: ‣ Passive and active design/engineering measures and procedures. ‣ *Occupational* exposure to radiation and radioactive products, and radiation protection programs responsibilities, including risks associated with characterisation, encapsulation, conditioning, quality assurance and certification of nuclear wastes. ‣ *Environmental* exposures and accumulation through the food chain. ‣ *Exposures* to the general public. ‣ *Transport* and receipt of nuclear wastes, including specific requirements to ensure safety during transport (certification, monitoring), and State and Local Government involvement and requirements. ‣ *Education* of workforce in relation to their environmental protection obligations, including radiological protection obligations. ▪ Occupational health and safety measures, including project site safety and measures to prevent or ensure radiation exposures are as low as reasonably achievable (ALARA) for employees	Chapter 13 Sections 7.6, 8.7–8.11, 9.4–9.8, 10.7, 12.3–12.10

- Possible establishment of a health and safety committee.
- Development and implementation of emergency management plans, emergency access routes, provision of emergency services and intervention requirements, including for external events such as extreme flood, earthquake, bushfires and falling debris associated with rocket or similar test vehicles associated with Defence facilities.
- Emergency evacuation procedures and requirements, as relevant, including of buffer zone (taking into account logistics, road layout and transport availability).
- Emergency training and exercises.
- Accident reporting, including against International Nuclear Event Scale.
- Responsibilities and liability in the event of an incident involving nuclear materials.
- Mitigation of any deleterious effects on economic, recreational, and community activities and resources, including disturbance and perceived loss of amenity.
- Actions aimed at addressing perceptions of risk from the repository (including community consultation and liaison).
- Measures to avoid or minimise radiation risks to local, regional, state and national communities, including along transport corridors.
- Measures to ensure land use restrictions are maintained.

Chapter 13
Sections 7.6, 8.7–8.11, 9.4–9.8, 10.7, 12.3–12.10

A.9.2 Monitoring Programs and Procedures

Monitoring programs to ensure that environment protection measures are applied effectively should be outlined. Examples of matters that should be addressed include:

- The program should be carefully designed and related to the predictions made in the EIS and the key environmental indicators that would demonstrate compliance and the potential ecological sustainability of the proposal.
- Details of monitoring objectives, programs and procedures.
- Proposed type, locations, frequency and intensity, and parameters of monitoring (including fixed monitoring stations, random, in situ and real time monitoring).
- Those responsible for monitoring programs should be identified and arrangements for making use of independent expertise discussed.
- Monitoring by state agencies.
- Provisions to ensure independent monitoring and analysis of samples, review and audit by regulatory authorities.
- Monitoring of the adequacy of emergency procedures developed to deal with accidental release of hazardous substances, fire, explosion and radiation exposure.
- There should be a statement of the procedures that will be put in place for reporting on monitoring programs
- Contingency measures in the event monitoring objectives are not met.
- Baseline monitoring programs to characterise environmental pathways and establish a radiological 'foot print'.
- Monitoring of all potential discharge routes to the environment.
- Monitoring of exposure pathways, including air and water media and potential biological pathways (for example sediments, plants and tissues in which radionuclides are known to concentrate).
- Monitoring of safety and health, including community health.
- Monitoring of wider community attitudes and concerns.

Chapter 13
Sections 8.12, 9.9, 12.11.

- There should be a description of any provisions made in project planning for the raising of initial environmental standards, response mechanisms, imposition of penalties and further remedial action if monitoring indicates that the project is causing unexpected environmental contamination or health concerns. — Chapter 13, Sections 8.12, 9.9, 12.11.
- Provision for liaison/consultation with relevant authorities and communities.
- Public disclosure of monitoring results and provision for public review of monitoring programs, if required.

A.10 Regulatory Regime and Operator Responsibilities

The discussion of the regulatory regime and operator responsibilities should include:

- The proposed ownership of the repository, including consideration of government or private sector operation. — Section 6.10
- Relevant legislation, standards, codes and policies (including those relevant to landfill and waste storage), together with measures proposed to ensure compliance, including to the extent appropriate with relevant internationally agreed conventions. These may include: — Section 3.2, 7.6.4
  - Australian Radiation Protection and Nuclear Safety Act 1999.
  - Nuclear Non-Proliferation (Safeguards) Act 1987.
  - Environment Protection (Nuclear Codes) Act 1978.
  - Occupational Health and Safety (Commonwealth Employment) Act 1991.
  - Code of Practice for the Near-surface Disposal of Radioactive Wastes in Australia, 1992.
  - Code of Practice for the Safe Transport of Radioactive Substances 1990.
  - National Health and Medical Research Council, Radiation Health Series No. 39 Recommendations for Limiting Exposure to Ionising Radiation 1995.
  - Recommendations and guidelines of the International Commission on Radiological Protection and the International Atomic Energy Agency, including Safety Series publications, Safety Standards and Radioactive Waste Safety Standards.
  - Relevant South Australian legislation, guidelines and policies, including planning requirements and emergency management.
  - Role and responsibility of South Australian agencies.
  - Relevant conventions such as the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.
  - Relevant policies of the Australian Nuclear Science and Technology Organisation and other nuclear waste producers.
  - Overview of regulatory infrastructure to oversee Commonwealth nuclear activities, including the role of ARPANSA.
  - Relevant Commonwealth legislation that regulates existing uses of the WPA, in particular the Defence Act 1903, Part VII of the Defence Force Regulations (DFR), DFR 35 and the Space Activities Act 1998.

A.11 Approvals and Licences

All approvals and licenses required under any legislation, including the EPBC Act, must be identified.

▪ This is to alert other relevant authorities as early as possible to their potential involvement in the project and to ensure an integrated approach to the granting of approvals. ▪ This list also identifies for the community the relevant authorities involved in the assessment and regulation of the proposal. ▪ Specific approval responsibilities of Commonwealth, state and local government authorities should be outlined. ▪ Conditions which may be placed on an approval to address identified impacts on NES matters should also be highlighted.	Section 1.2, 3.3

A.12 Financial Arrangements for the Construction, Operation and Rehabilitation of the Repository

The proposed financial arrangements for disposal and monitoring of wastes, rehabilitation and emergency cleanup, including consideration of 'user pays' should be discussed.	Section 6.11

A.13 Conclusion

An overall conclusion as to the environmental acceptability of the proposal should be provided, including discussion on:

▪ Compliance principles of ESD and the objectives and requirements of the EPBC Act. ▪ Reasons justifying undertaking the proposal in the manner proposed. ▪ Measures proposed or required by way of offset or compensation for any impacts on NES criteria, and estimated financial costs, should be highlighted.	Chapter 14
Recommendations should be made regarding inspection procedures to be followed after the repository has been completed.	Chapter 13
▪ In addition, Principles of Radiation Protection such as justification, optimisation and As Low As Reasonably Achievable (ALARA) need to be addressed in all stages of the proposal.	Section 3.1, 5.3, 12.11

A.14 Attachment A: Object of EPBC Act and ESD Considerations

The following is an extract from the EPBC Act.

3. Objects of Act

The objects of this Act are to:

(a) provide for the protection of the environment, especially those aspects of the environment that are matters of national environmental significance; and
(b) promote ecologically sustainable development through the conservation and ecologically sustainable use of natural resources; and
(c) promote the conservation of biodiversity; and
(d) promote a cooperative approach to the protection and management of the environment involving governments, the community, land-holders and indigenous peoples; and
(e) recognise the role of indigenous people in the conservation and ecologically sustainable use of Australia's biodiversity; and
(f) promote the use of indigenous peoples' knowledge of biodiversity with the involvement of, and in cooperation with, the owners of the knowledge.

3A. Principles of Ecologically Sustainable Development (ESD)

The following principles are principles of ecologically sustainable development:

(a) decision making processes should effectively integrate both long term and short term economic, environmental, social and equitable considerations;
(b) if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation;
(c) the principle of inter generational equity - that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations;
(d) the conservation of biological diversity and ecological integrity should be a fundamental consideration in decision making;
(e) improved valuation, pricing and incentive mechanisms should be promoted.

391 Minister Must Consider Precautionary Principle in Making Decisions

Taking account of precautionary principle

(1) The Minister must take account of the precautionary principle in making a decision listed in the table in subsection (3), to the extent he or she can do so consistently with the other provisions of this Act.

Precautionary principle

(2) The ***precautionary principle*** is that lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment where there are threats of serious or irreversible environmental damage.

A.15 Attachment B: NES Criteria

The following is an extract from relevant NES criteria.

18 Actions with Significant Impact on Listed Threatened Species or Endangered Community Prohibited Without Approval

Species that are extinct in the wild

(1) A person must not take an action that:
- (a) has or will have a significant impact on a listed threatened species included in the extinct in the wild category; or
- (b) is likely to have a significant impact on a listed threatened species included in the extinct in the wild category.

Critically endangered species

(2) A person must not take an action that:
- (a) has or will have a significant impact on a listed threatened species included in the critically endangered category; or
- (b) is likely to have a significant impact on a listed threatened species included in the critically endangered category.

Endangered species

(3) A person must not take an action that:
- (a) has or will have a significant impact on a listed threatened species included in the endangered category; or
- (b) is likely to have a significant impact on a listed threatened species included in the endangered category.

Vulnerable species

(4) A person must not take an action that:
- (a) has or will have a significant impact on a listed threatened species included in the vulnerable category; or
- (b) is likely to have a significant impact on a listed threatened species included in the vulnerable category.

Critically endangered communities

(5) A person must not take an action that:
- (a) has or will have a significant impact on a listed threatened ecological community included in the critically endangered category; or
- (b) is likely to have a significant impact on a listed threatened ecological community included in the critically endangered category.

Endangered communities

(6) A person must not take an action that:
- (a) has or will have a significant impact on a listed threatened ecological community included in the endangered category; or
- (b) is likely to have a significant impact on a listed threatened ecological community included in the endangered category.

21 Requirement for Approval of Nuclear Actions

(1) A constitutional corporation, the Commonwealth or Commonwealth agency must not take a nuclear action that has, will have or is likely to have a significant impact on the environment.

(2) A person must not, for the purposes of trade or commerce:
- (a) between Australia and another country; or
- (b) between 2 States; or
- (c) between a State and a Territory; or
- (d) between 2 Territories;

take a nuclear action that has, will have or is likely to have a significant impact on the environment.

(3) A person must not take in a Territory a nuclear action that has, will have or is likely to have a significant impact on the environment.

22. What is a *nuclear action*?

(1) In this Act:

Nuclear action means any of the following:
- (a) establishing or significantly modifying a nuclear installation;
- (b) transporting spent nuclear fuel or radioactive waste products arising from reprocessing;
- (c) establishing or significantly modifying a facility for storing radioactive waste products arising from reprocessing;
- (d) mining or milling uranium ore;
- (e) establishing or significantly modifying a large scale disposal facility for radioactive waste;
- (f) decommissioning or rehabilitating any facility or area in which an activity described in paragraph (a), (b), (c), (d) or (e) has been undertaken;
- (g) any other action prescribed by the regulations.

Nuclear installation means any of the following:
- (a) a nuclear reactor for research or production of nuclear materials for industrial or medical use (including critical and subcritical assemblies);
- (b) a plant for preparing or storing fuel for use in a nuclear reactor as described in paragraph (a);
- (c) a nuclear waste storage or disposal facility with an activity that is greater than the activity level prescribed by regulations made for the purposes of this section;
- (d) a facility for production of radioisotopes with an activity that is greater than the activity level prescribed by regulations made for the purposes of this section.

Note: A nuclear waste storage or disposal facility could include a facility for storing spent nuclear fuel, depending on the regulations.

Radioactive waste means radioactive material for which no further use is foreseen.

Reprocessing means a process or operation to extract radioactive isotopes from spent nuclear fuel for further use.

Spent nuclear fuel means nuclear fuel that has been irradiated in a nuclear reactor core and permanently removed from the core.

Large scale disposal facility for radioactive waste means, if regulations are made for the purposes of this definition, a facility prescribed by the regulations.

28 Requirement for Approval of Activities of Commonwealth Agencies Significantly Affecting the Environment

(1) The Commonwealth or a Commonwealth agency must not take inside or outside the Australian jurisdiction an action that has, will have or is likely to have a significant impact on the environment inside or outside the Australian jurisdiction.

Note: This does not apply to decisions to authorise activities. See Subdivision A of Division 1 of Part 23.

(2) Subsection (1) does not apply to an action if:
- (a) an approval of the taking of the action by the Commonwealth or Commonwealth agency is in operation under Part 9 for the purposes of this section; or
- (b) Part 4 lets the Commonwealth or Commonwealth agency take the action without an approval under Part 9 for the purposes of this section; or
- (c) the action is one declared by the Minister in writing to be an action to which this section does not apply; or
- (d) there is in force a decision of the Minister under Division 2 of Part 7 that this section is not a controlling provision for the action and, if the decision was made because the Minister believed the action would be taken in a manner specified in the notice of the decision under section 77, the action is taken in that manner; or
- (e) the action is an action described in subsection 160(2) (which describes actions whose authorisation is subject to a special environmental assessment process).

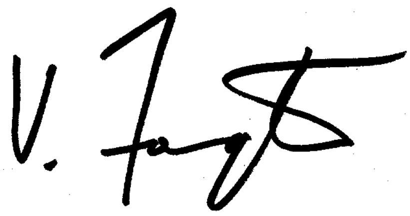
(3) The Minister may make a written declaration that actions are actions to which this section does not apply, but only if he or she is satisfied that it is necessary in the interests of:
- (a) Australia's defence or security; or
- (b) preventing, mitigating or dealing with a national emergency.

(4) The Minister may make a written declaration that all actions, or a specified class of actions, taken by a specified Commonwealth agency are actions to which this section does not apply.

(5) The Minister may make a declaration under subsection (4) relating to a Commonwealth agency's actions only if he or she is satisfied that, in taking the actions to which the declaration relates, the agency must comply with the law of a State or Territory dealing with environmental protection.

A.16 Attachment C: Certificate of Compliance

Submission of Environmental Impact Statement/Public Environment Report
Prepared under the *Environment Protection and Biodiversity Conservation Act 1999*

EIS/PER prepared by	
Name	PPK Environment & Infrastructure
Qualifications	Consulting Engineers, Scientists and Planners
Address	101 Pirie Street, Adelaide SA 5001.
In respect of (general description of action)	Sections 21 and 22: Nuclear Action – establishing a facility for disposal of low level and short-lived intermediate level radioactive waste. Section 28: Commonwealth Action – requirement for approval of an action of significance by the Commonwealth.
Proposed Action (short name)	Low level and short-lived intermediate level radioactive waste repository
Proponent name	Department of Education, Science and Training
Proponent address	16 Mort Street, Canberra, ACT 2601
Land to be developed (particulars of land to be developed. For example lot no., vol/fol, map reference, etc.)	Site 52a, near Koolymilka, Woomera Prohibited Area, South Australia, easting/northing coordinates at site centre 637,118.38E, 6,573,707.48N. Alternative sites : - Site 40a, about 20 km east of Woomera, coordinates at site centre 695,222.13E, 6,545,570.63N; and Site 45a, about 50 northeast of Woomera, coordinates at site centre 705,973.61E, 6,586,975.27N
Certificate	I certify that I have prepared the contents of this Statement/Report and to the best of my knowledge ▪ it is in accordance with the guidelines prepared under Section 97/102 of the *Environment Protection and Biodiversity Conservation Act 1999*, and ▪ it is true in all material particulars and does not by its presentation or omission of information, materially mislead.
Signature	
Name	V. Farrington
Date	31 May 2002

A.17 Attachment D: Schedule 4 Matters to be Addressed by Draft Public Environment Report and Environmental Impact Statement (Regulation 5.04)

1. General Information

1.01 The background of the action including:

(a) the title of the action;
(b) the full name and postal address of the designated proponent;
(c) a clear outline of the objective of the action;
(d) the location of the action;
(e) the background to the development of the action;
(f) how the action relates to any other actions (of which the proponent should reasonably be aware) that have been, or are being, taken or that have been approved in the region affected by the action;
(g) the current status of the action;
(h) the consequences of not proceeding with the action.

2. Description

2.01 A description of the action, including:

(a) all the components of the action;
(b) the precise location of any works to be undertaken, structures to be built or elements of the action that may have relevant impacts;
(c) how the works are to be undertaken and design parameters for those aspects of the structures or elements of the action that may have relevant impacts;
(d) relevant impacts of the action;
(e) proposed safeguards and mitigation measures to deal with relevant impacts of the action;
(f) any other requirements for approval or conditions that apply, or that the proponent reasonably believes are likely to apply, to the proposed action;
(g) to the extent reasonably practicable, any feasible alternatives to the action, including:
   (i) if relevant, the alternative of taking no action;
   (ii) a comparative description of the impacts of each alternative on the matters protected by the controlling provisions for the action;
   (iii) sufficient detail to make clear why any alternative is preferred to another;
(h) any consultation about the action, including:
   (i) any consultation that has already taken place;
   (ii) proposed consultation about relevant impacts of the action;
   (iii) if there has been consultation about the proposed action any documented response to, or result of, the consultation;
   (iv) identification of affected parties, including a statement mentioning any communities that may be affected and describing their views.

3. Relevant Impacts

3.01 Information given under paragraph 2.01 (d) must include:

(a) a description of the relevant impacts of the action;
(b) a detailed assessment of the nature and extent of the likely short term and long term relevant impacts;
(c) a statement whether any relevant impacts are likely to be unknown, unpredictable or irreversible;
(d) analysis of the significance of the relevant impacts;
(e) any technical data and other information used or needed to make a detailed assessment of the relevant impacts.

4. Proposed Safeguards and Mitigation Measures

4.01 Information given under paragraph 2.01 (e) must include:

(a) a description, and an assessment of the expected or predicted effectiveness of, the mitigation measures;
(b) any statutory or policy basis for the mitigation measures;
(c) the cost of the mitigation measures;
(d) an outline of an environmental management plan that sets out the framework for continuing management, mitigation and monitoring programs for the relevant impacts of the action, including any provisions for independent environmental auditing;
(e) the name of the agency responsible for endorsing or approving each mitigation measure or monitoring program;
(f) a consolidated list of mitigation measures proposed to be undertaken to prevent, minimise or compensate for the relevant impacts of the action, including mitigation measures proposed to be taken by State governments, local governments or the proponent.

5. Other Approvals and Conditions

5.01 Information given under paragraph 2.01 (f) must include:

(a) details of any local or State government planning scheme, or plan or policy under any local or State government planning system that deals with the proposed action, including:
  (i) what environmental assessment of the proposed action has been, or is being, carried out under the scheme, plan or policy;
  (ii) how the scheme provides for the prevention, minimisation and management of any relevant impacts;
(b) a description of any approval that has been obtained from a State, Territory or Commonwealth agency or authority (other than an approval under the Act), including any conditions that apply to the action;
(c) a statement identifying any additional approval that is required
(d) a description of the monitoring, enforcement and review procedures that apply, or are proposed to apply, to the action.

6. Environmental Record of Person Proposing to Take the Action

6.01 Details of any proceedings under a Commonwealth, State or Territory law for the protection of the environment or the conservation and sustainable use of natural resources against:

(a) the person proposing to take the action; and
(b) for an action for which a person has applied for a permit, the person making the application.

6.02 If the person proposing to take the action is a corporation, details of the corporation's environmental policy and planning framework.

7. Information Sources

7.01 For information given in a draft public environment report or environmental impact statement, the draft must state:

(a) the source of the information; and
(b) how recent the information is; and
(c) how the reliability of the information was tested; and
(d) what uncertainties (if any) are in the information.

APPENDIX B

Appendix B

RADIOACTIVE WASTE INVENTORY

B

Appendix B
Radioactive Waste Inventory

TABLE B.1 Estimated inventory of low level and short-lived intermediate level waste to be disposed of at the repository (key radionoclides) as at April 2002

State / Waste holder	Estimated total volume (m^3) (1)	Activity (Bq) in total volume(2)	^{3}H	^{60}Co	^{90}Sr	^{137}Cs	^{226}Ra	^{232}Th	^{238}U	^{241}Am	$^{226}Ra/Be$	$^{241}Am/Be$
Queensland	45 (1)	8.83E+11	2.97E+11	8.61E+10	5.56E+10	4.39E+11	5.30E+09	2.00E+03	2.40E+03	3.27E+08	7.30E+07	
Victoria	26 (1)	2.59E+11	6.97E+10	1.78E+09	1.70E+10	3.59E+10	2.16E+10	8.39E+05	6.53E+06	1.05E+11	2.16E+10	4.11E+09
NSW	26 (1)	1.37E+09	6.10E+08	1.48E+07	3.69E+08	2.43E+08	8.12E+07		2.21E+03	3.25E+06	5.00E+06	3.70E+07
Tasmania	15 (1)	6.03E+10	6.03E+10	8.00E+06		2.00E+06				3.20E+05		
South Aust.	20 (1)	1.70E+09		2.81E+06	1.7E+04	9.53E+08	3.70E+08	3.70E+08		8.15E+02		
ACT	3 (1)	4.20E+11	4.00E+11	2.00E+07	2.00E+10	9.00E+07	2.00E+07	2.00E+07	2.00E+05	4.03E+06		
NT	16 (1)	9.05E+11	9.00E+11	2.62E+09	3.5E+04	2.18E+09	3.00E+05		2.00E+05	4.03E+06		
Defence:												
– St Marys (SA)	20	3.66E+10		8.23E+09	8.05E+09	1.25E+10	6.70E+09					
– Other (SA/Vic/NSW)	190	7.25E+11	5.64E+11	1.12E+09			6.25E+09	2.01E+08	4.13E+10			
ANSTO (NSW)	1,320	6.79E+11	1.70E+10	3.33E+11	1.44E+10	2.84E+11	2.80E+09	3.05E+09	1.40E+10	2.40E+09		
CSIRO – Soils (SA)	2,010	2.79E+08					1.32E+07	2.00E+08	1.32E+07			
CSIRO – Other (Vic/ACT/NSW)	9	6.95E+11	1.65E+05	1.86E+11	3.58E+09	5.02E+11						
TOTAL	**3,700**	4.67 E+12	2.31E+12	6.19E+11	1.19E+11	1.28E+12	4.31E+10	3.84E+09	5.53E+10	1.08E+11	2.17E+10	4.14E+9

(1) State/Territory estimated volumes are nominal quantities held by the regulator, plus hospitals/universities and industry volumes. They include all waste that is expected to be disposed of in the repository (for estimated categories A, B and C). The volumes are in conditioned form.

(2) Activities and volumes given are for items that have been previously classed as category A, B or C and those that have been provisionally estimated as being category A, B and C. (There are neither mass nor volume data for Queensland and NT wastes, and no mass data for SA and NSW wastes.)

APPENDIX C

Appendix C

PHYSICAL ENVIRONMENT

C1 Topography, Groundwater Contours and Stratigraphy
Bureau of Rural Sciences

C2 Groundwater Recharge Considerations
Bureau of Rural Sciences

C3 Hydraulic Conductivity Tests
PPK Environment & Infrastructure

C4 Cap and Liner Seepage Assessment
PPK Environment & Infrastructure

C5 Unsaturated Zone Modelling
PPK Environment & Infrastructure

C

Appendix C1
Topography, Groundwater Contours and Stratigraphy

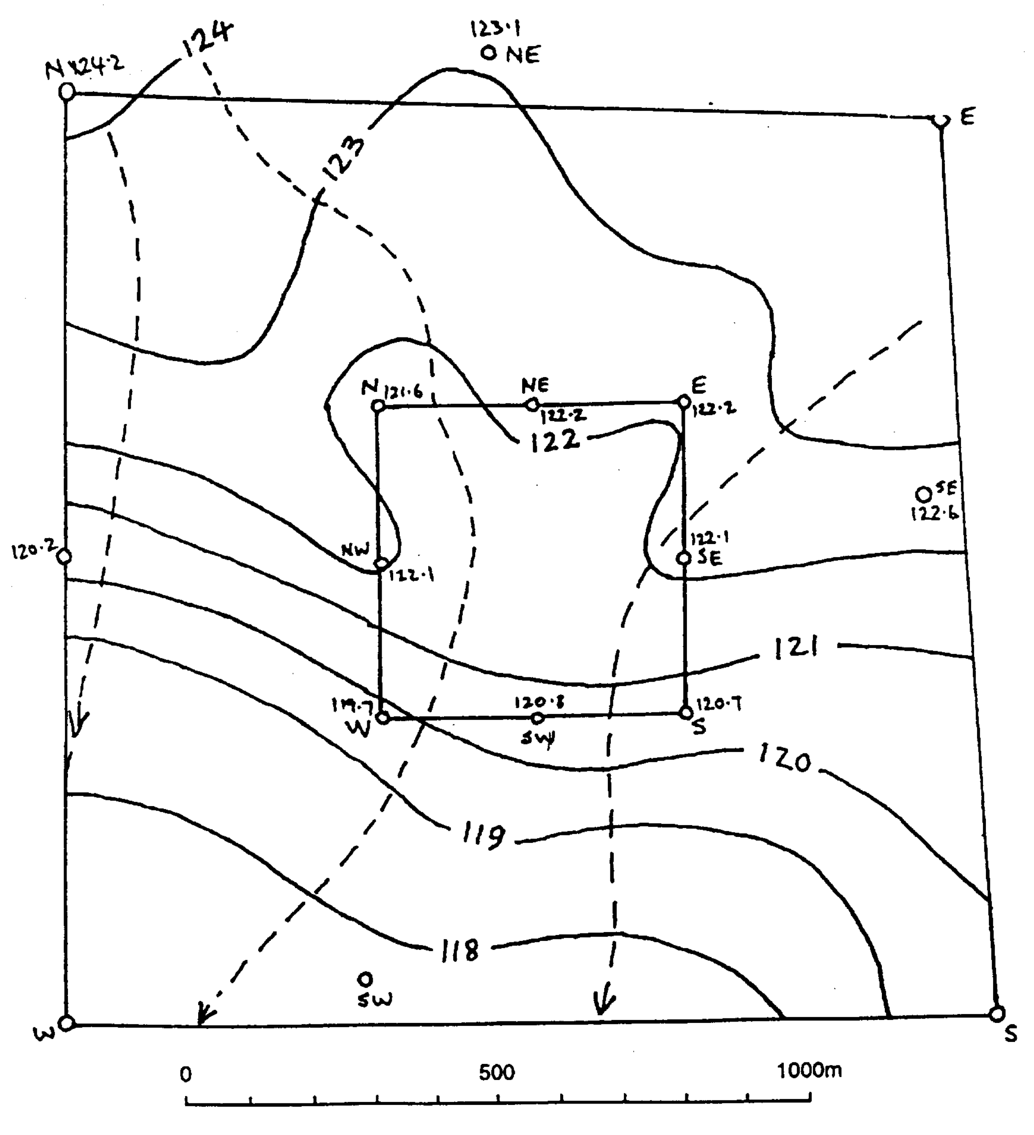


FIGURE C1.1
Site 40a: Watertable contours (mASL) and flowlines, November 2000

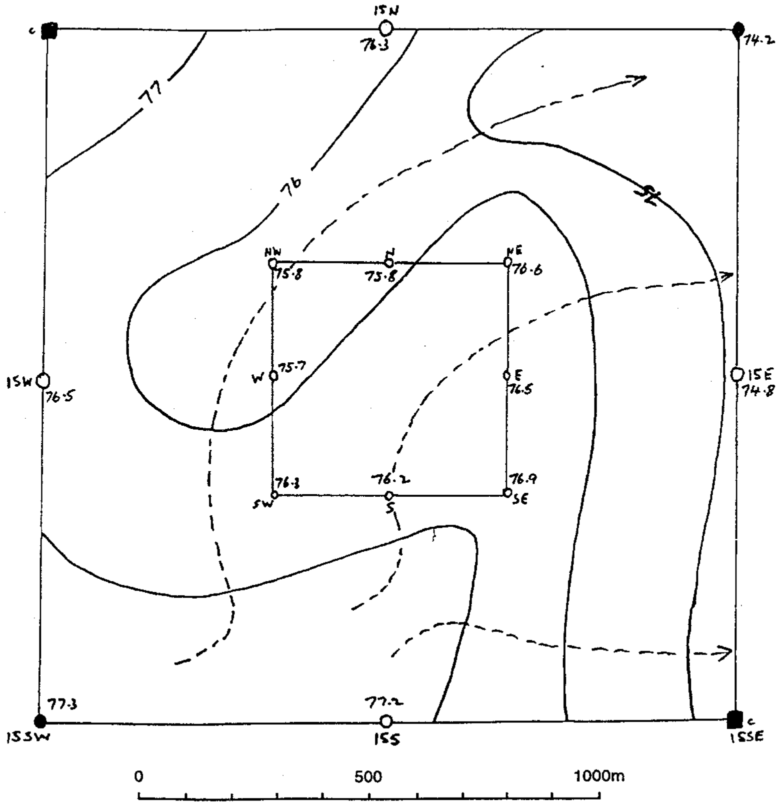


FIGURE C1.2
Site 45a: Watertable contours and flowlines, September 2000

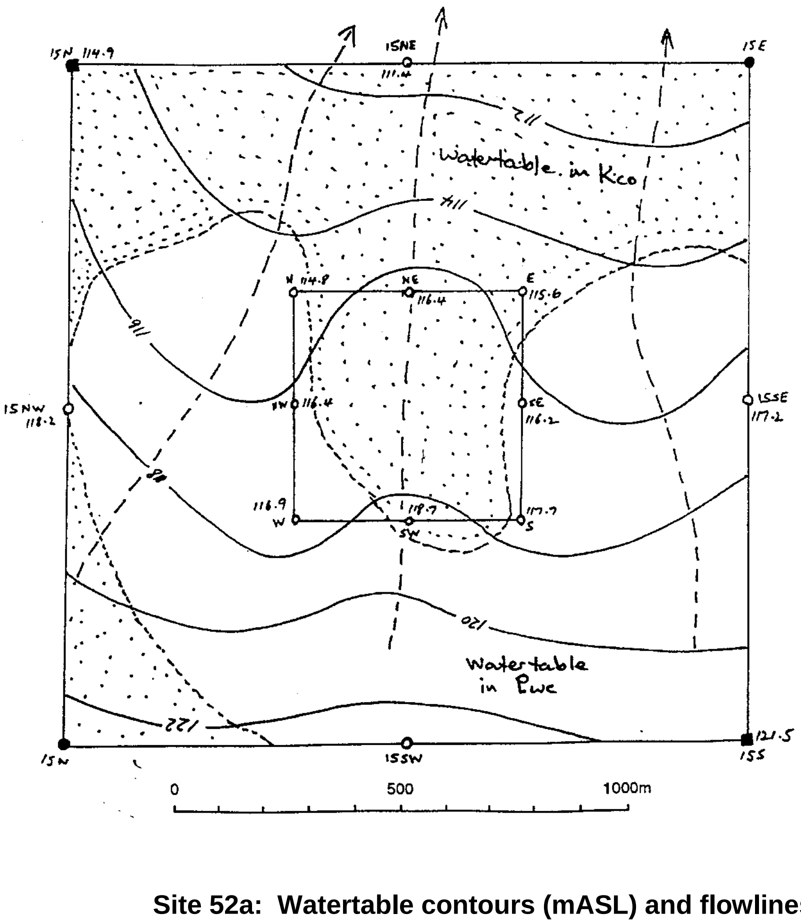


FIGURE C1.3
Site 52a: Watertable contours (mASL) and flowlines, September 2000

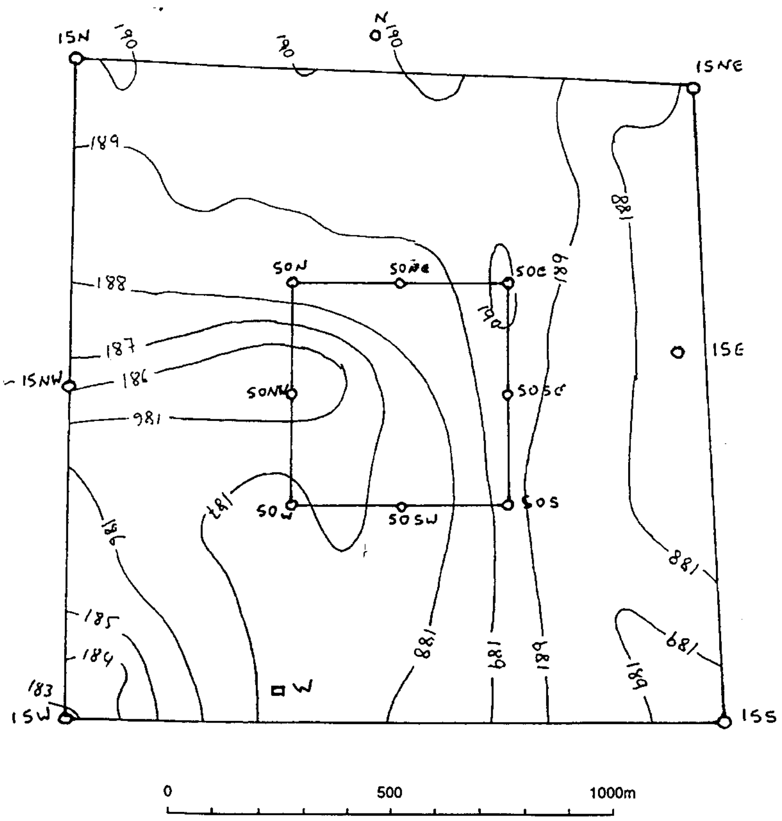


FIGURE C1.4
Site 40a: Topographic contours (mASL)

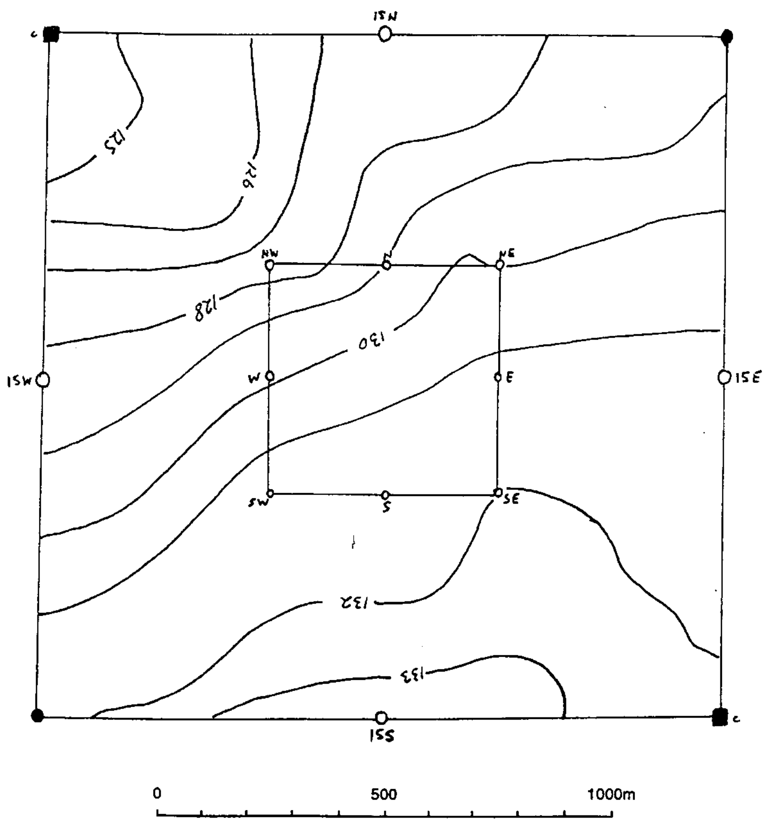


FIGURE C1.5
Site 45a: Topographic contours (mASL)

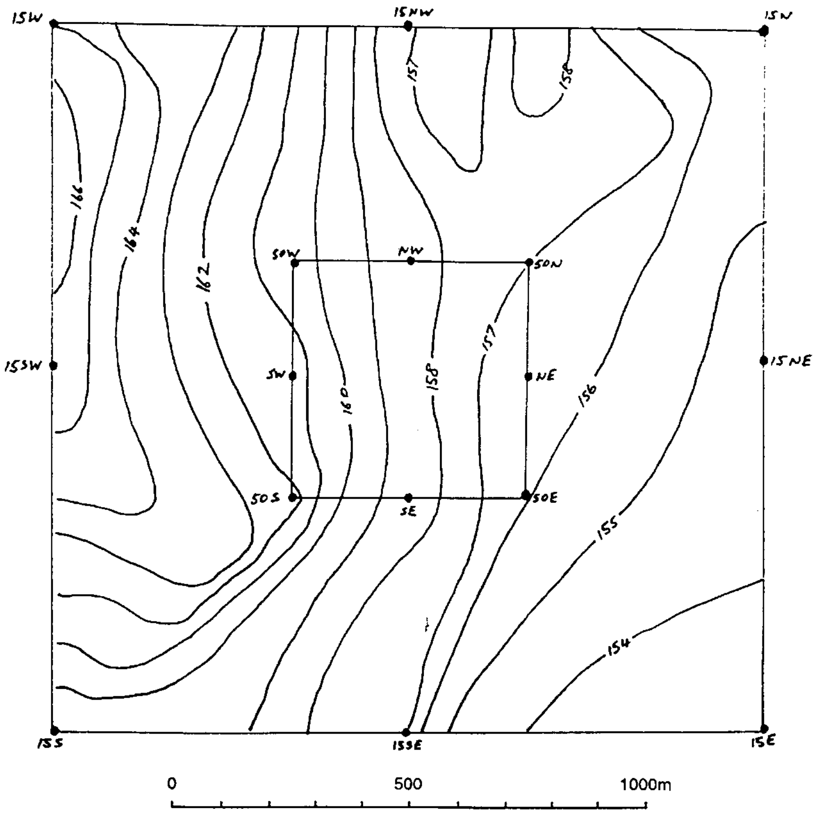


FIGURE C1.6
Site 52a: Topographic contours (mASL)

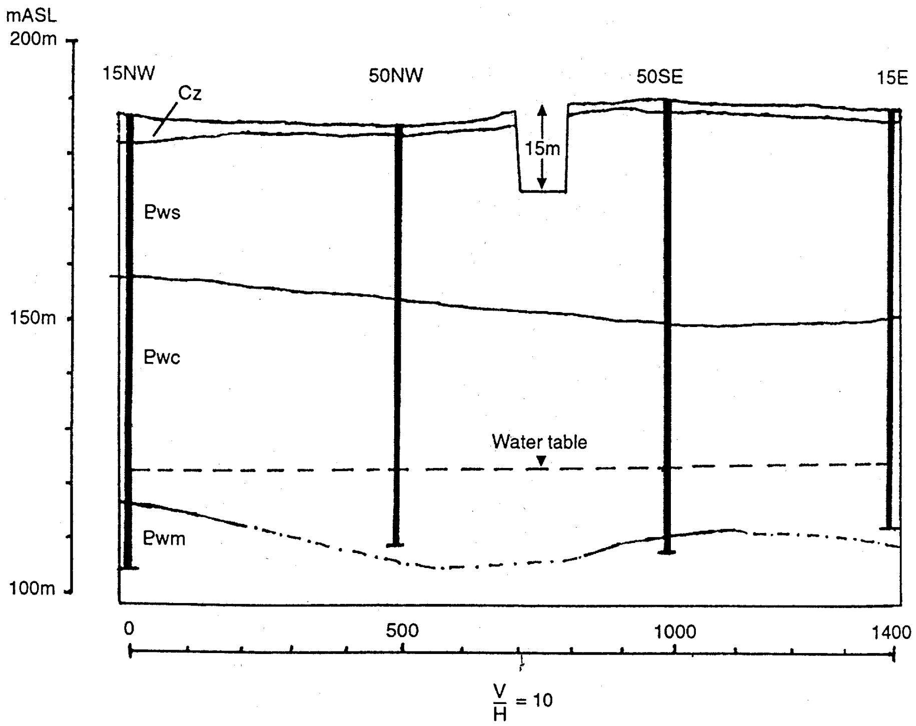


FIGURE C1.7
Site 40a: NW–SE stratigraphic section

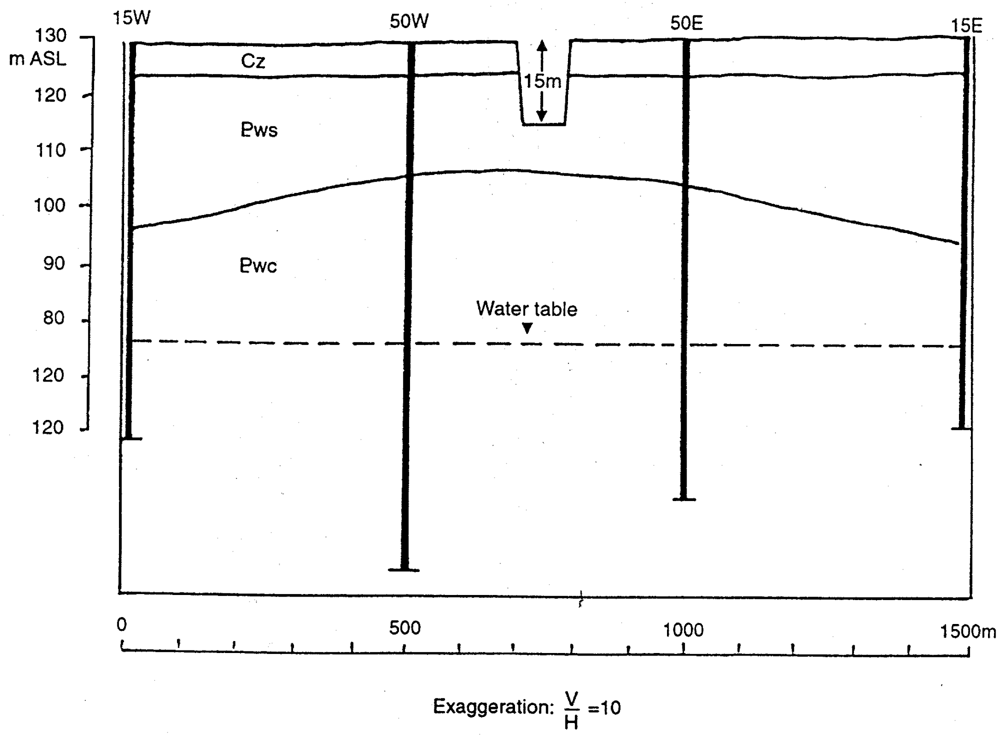


FIGURE C1.8
Site 45a: W–E stratigraphic section

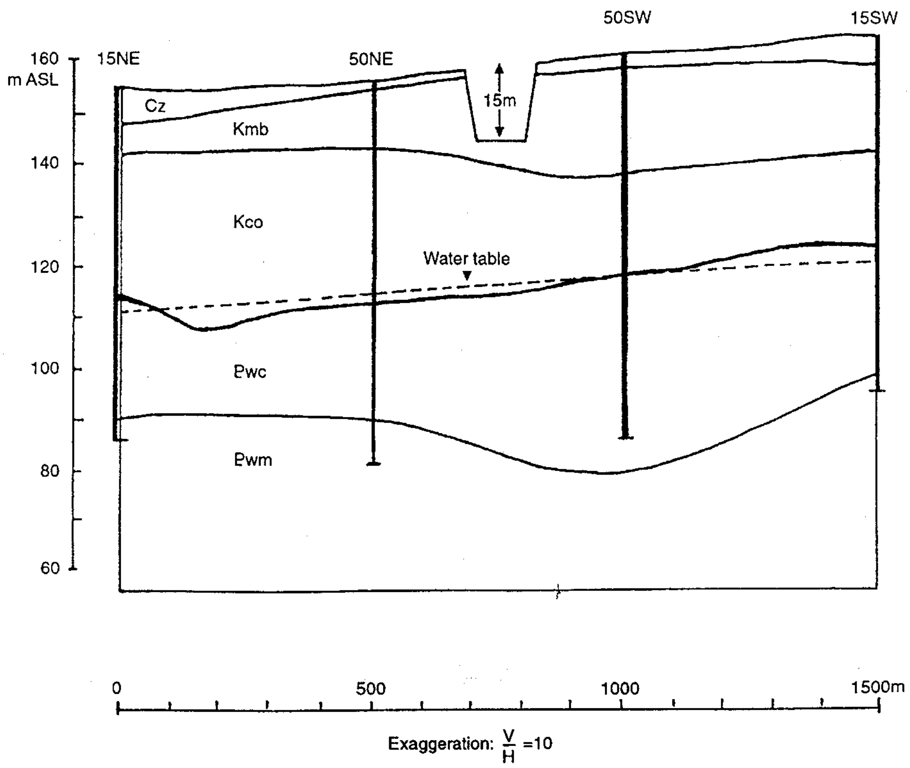


FIGURE C1.9
Site 52a: NE–SW stratigraphic section

Appendix C2 Groundwater Recharge Considerations

This appendix is an excerpt from Bureau of Rural Sciences, 2001, Australia's National Radioactive Waste Repository — Phase 3 Site Assessment and Stage 3 Drilling: Stage 3 Assessment Report. Full text and data available from the website http://www.dest.gov.au/radwaste/publications.htm including the appendices referred to below.

C2.1 Introduction

Three methods were used to estimate groundwater recharge:

1. chloride mass balance in the saturated zone
2. chloride mass balance (coupled with moisture and bulk density) profiling in the unsaturated zone
3. groundwater age estimation using the unstable isotopes ^{36}Cl and ^{14}C.

In related experiments, CSIRO/ANSTO (Harries et al. 1998) measured deep drainage at 1.5 m beneath clays at Pimba. Deep drainage below a non-vegetated desert loam was estimated to be 0.2 mm/yr and two orders of magnitude less for a vegetated (*Atriplex*) surface (deep drainage provides an upper bound for recharge).

C2.2 Chloride Mass Balance — Saturated Zone

Chloride mass balance in the saturated zone is the simplest technique for recharge estimation. The method assumes one-dimensional piston flow and produces a lumped historic recharge rate damped against variations in rainfall and weather patterns, and chloride input. The method also assumes that evaporated rainfall and dryfall are the sole sources of chloride to the system. Using an 'average annual' rainfall of 180 mm at Sites 40a and 45a, and 190 mm at Site 40a, coupled with an average annual atmospheric Cl input of 4 mg/L (combined wet and dry fall), and mean Cl concentrations of 13,000, 12,000 and 8500 mg/L in groundwaters at Sites 40a, 45a and 52a respectively, the chloride mass balance method gives a recharge rate of 0.06 mm/yr at Sites 40a and 45a, and 0.09 mm/yr at Site 52a. Within the limits of accuracy of the method, the chloride mass balance technique thus gives indicative recharge rates of the order of 0.05 mm/yr in areas underlain by @ws/@wc and about 0.1 mm/yr in an area underlain by Kmb/Kco/@wc. If effective porosity of @ws, @wc and Kmb is assumed to be 0.01, and 0.05 in Kco, the wetting front velocity is about 6 mm/yr at Sites 40a and 45a, and 3 mm/yr at Site 52a. Hence it would take 11,000 years for infiltration through the 67 m thick unsaturated zone at Site 40a, 9000 years to infiltrate the 55 m thick unsaturated zone at Site 45a and 14,000 years through 41 m of unsaturated zone at Site 52a.

C2.3 Chloride Mass Balance — Unsaturated Zone

For the unsaturated zone profiling, cubes of diameter 3–5 cm were cut at selected intervals from the drillcore at two diagonally opposite cored holes in the outer squares at Sites 40a, 45a and 52a. Chloride concentrations in the unsaturated zone, calculated from 1:5 dilutions, are shown in the full web report as Appendix 6.1. Since Sites 40a and 45a are composed of similar lithologies, they will be described first.

At Site 40a, chloride concentrations of the order of 35,000 mg/L were measured in the surface clays of both drillholes (40aE and 40aW). Very high chloride concentrations were recorded in the Simmens Quartzite, peaking at 0.5 kg/L at 11m depth in both drillholes. These values are probably more apparent than real because of the extremely low gravimetric moistures in the quartzite matrix. Thereafter, there was negligible correlation in depth vs chloride concentrations between the two drillholes. In 40aE, chloride concentrations fell to around 25,000 mg/L between 15 and 10 m before rising to 0.35 kg/L in a secondary peak between 24 and 35 m; the underlying Corraberra Sandstone had chloride concentrations of around 0.1 kg/L down to 42 m and then fell steeply to around 5000 mg/L to the bottom of the hole at 49 m. In 40aW, chloride concentrations in the Simmens Quartzite exceeded 0.1 kg/L down to 25 m, whereupon they fell to around 35,000 mg/L to the contact with the Corraberra Sandstone at 34 m; chlorinities in @wc were generally higher than 0.1 kg/L throughout the cored section to 51 m.

Chloride concentrations in the surface clays at Site 45a vary from 30,000 mg/L at drillhole 45aNW to in excess of 100,000 mg/L at 45aSE. As at Site 40a, chlorinities in the Simmens Quartzite are highly variable between drillholes at Site 45a. In drillhole 45aNW, the background chloride concentration in @ws is around 5000 mg/L apart from spikes of 50,000 mg/L at 6 m and 30,000 mg/L at 16 m. Background chloride concentrations then rise gradually below the Corraberra Sandstone contact (at 24 m) to 9000 mg/L at the bottom of the hole at 43 m, with a spike of 48,000 mg/L at 36 m. However in drillhole 45aSE, chlorinities are reasonably constant between 30,000 and 40,000 mg/L throughout @ws. Below the @wc contact at 25 m, chloride concentrations show a sustained rise, peaking close to 0.6 kg/L at 36–38 m before falling to around 30,000 mg/L at the bottom of the hole at 47 m. Thus, the essential difference between the Site 45a drillholes is that 45aNW contains layers of lower chlorinity water in @ws than 45aSE, and the latter contains appreciably higher chloride concentrations in @wc.

Volumetric moisture contents for the cores from Sites 40a and 45a are shown in web report Appendix 6.2. Clay bands in @ws in drillhole 40aE have volumetric moistures ranging between 0.2 and 0.4, whereas moistures in the quartzite are very low, ~0.01. Two clay bands near the base of @ws in drillhole 40aW have moisture contents between 0.4 and 0.5, and again very low moistures in the quartzite. Clayey bands in @wc in 40aE have moisture contents ~0.2 and very low (~0.01) moistures in the silicified sandstone beds, whereas @wc moistures are uniformly low (0.01 to 0.04) in 40aW.

Volumetric moisture contents in @ws at 45aNW show a similar pattern to Site 40a, with moistures in the range ~0.25 to ~0.35 in the clay bands and around 0.01 in the quartzite layers. In common with Site 40a, volumetric moistures in the @ws clay seams tend to be higher in the bottom half of the unit, reflecting the higher plasticity and greater water holding capacity of the (greenish) illite clays over kaolinite. In 45aSE, the generally higher volumetric moistures (0.2 to 0.35) in @ws are a consequence of the greater proportion of clay relative to 45aNW. As in drillhole 40aE, volumetric moisture contents in @wc at Site 45a are erratic, ranging from 0.2 to 0.3 in clayey layers to ~0.01 in clean silicified sandstone beds.

Web report Appendix 6.3 shows plots of cumulative water against cumulative chloride. Drillholes 40aE and 40aW show a similar multi-segmented form. Steep rises in cumulative chloride occur in both drill cores in certain sections of @ws (7–16 m and 19–24 m in 40aE, 10–25 m in 40aW) coinciding with quartzite-rich zones having negligible clay bands. As noted earlier, the calculated chloride concentrations derived from 1:5 dilutions of the quartzite pore fluids are suspect because small errors in 1:5 eluent concentration or in gravimetric moisture content have the potential to generate large errors in the converted data.

If recharge is solely by piston flow and the chloride flux at ground surface has been constant, cumulative chloride as a function of cumulative water should be a straight line. Therefore, either (1) the assumption of recharge by piston flow at Site 40a is not valid, or (2) the chloride flux has not been constant through time, or (3) not all the chloride comes from atmospheric sources. An alternative explanation is the cumulative chloride values in the quartzite-rich zones of @ws are invalid, i.e. the chloride mass balance method is strictly not applicable here. If this is correct, we may still use the chloride and moisture characteristics of the clayey zones of @ws to estimate recharge. This gives a reasonably uniform estimated recharge of 0.02 mm/yr for both 40aE and 40aW, assuming a chloride accession rate of 0.76/g^2/yr.

The slope of the cumulative chloride curve for drillhole 45aSE (web report Appendix 6.3) is about 4 times that of 45aNW, but both plots display a greater degree of linearity than the Site 40a drillholes. Also, cumulative water for Site 45a is about double that of Site 40a. Both of these factors reflect the generally higher clay content in @ws at Site 45a relative to Site 40a. Again, assuming piston flow recharge and a constant chloride flux rate through time, recharge rates of 0.02 mm/yr for drillhole 45aSE are indicated, whereas 45aNW gives a recharge rate of 0.02 mm/yr through the surface clay, but an apparent admittance rate of 0.17 mm/yr through @ws. This seems to indicate preferential flow or possibly a different palaeorecharge regime, and illustrates the marked salinity variations in the unsaturated zone across the Site.

Chloride concentrations are between 50,000 and 100,000 mg/L in the surface clays at Site 52a (web report Appendix 6.1), similar to Site 45a. Thereafter, chloride concentrations decrease in the Bulldog Shale, to nearly 30,000 mg/L through the thin section of Kmb at drillhole 52aNE, and to an average of 20,000 mg/L in drillhole 52aSW. The generally downward trend in chloride concentration with depth continues through the Cadna-owie Formation — in drillhole 52aNE, average chlorinity is 25,000 mg/L in the upper half of Kco (to 31 m depth) and then displays a sustained fall to 7000 mg/L, continuing into @wc. Apart from an anomalous spike of 80,000 mg/L at 23.5 m, the same general pattern of decreasing Cl with depth is displayed in Kco at drillhole 52aSW. Here, chlorinity drops from around 20,000 mg/L at the top of Kco to 12,000 mg/L at the base at 48 m. The downward trend continues into @wc, where the average pore-water chloride concentration is 8000 mg/L.

Chloride profiles in drillholes 52aNE and 52aSW display greater homogeneity than at Sites 40a and 45a, a consequence of different lithologies, and are easier to interpret. At 52a, the bulge in chloride in the top 1.5 m represents concentration by evapo-transpiration of vegetation (Atriplex). The background level of ~20,000 mg/L in Kmb and the upper section of Kco represents the equilibrium chloride concentration below the root zone, and it is this value which should be used for mass balance calculations. The downward trends in chloride concentration in the lower section of Kco and in @wc represent diffusive loss of chloride to the watertable (the watertable lies about 40 m below ground surface).

Volumetric moisture contents in Kmb beneath the root zone are reasonably uniform, between 0.4 and 0.5, in both 52aNE and 52aSW (web report Appendix 6.2). Kco is characterised by generally erratic moistures, ranging from ~0.4 in clayey bands to ~0.05 in the clean sand(stone) layers — drillhole 52aNE shows more uniformity than 52aSW because of the former’s higher sand proportion. Both of the 52a cores show rising volumetric moistures in the basal section of Kco and in @wc.

In contrast to Sites 40a and 45a, cumulative chloride as a function of cumulative water is approximately linear throughout the unsaturated zone at Site 52a (web report Appendix 6.3). Mass balance calculations give a recharge rate of 0.03 mm/yr for 52aNE and 0.05 mm/yr for 52aSW (Kmb and upper Kco). Inflexion points in the cumulative plots occur where diffusive losses of chloride to the fresher watertable start to operate in the basal part of the Kco aquifer.

C2.4 Groundwater Age Estimation — ^{36}Cl and ^{14}C

The radioisotopes ^{36}Cl and ^{14}C have half-lives of 300,000 and 5730 years, respectively. Nine regional groundwater waters were analysed for ^{36}Cl by accelerator mass spectrometry at the Australian National University; 10 samples were analysed for radiocarbon by counting at CSIRO (web report Appendix 7). The results are plotted against standing water level for the respective bores in Figure C2.1.

Of the 10 samples analysed for ^{14}C, only 4 exhibited levels that might be considered as above background levels in groundwaters. This level is generally taken as 2 per cent Modern Carbon (pMC) and gives a limiting age of >30,000 years for the carbonate dissolved in the waters. The four samples which contained greater than 2 pMC were 33S, 52aNW, 14aSE and 10N and their calculated ages ranged from 19,000 years BP (14aSE) to 29,000 (52aNW). The uniform, negative, δ^{13}C values and low alkalinities indicate minimal mixing with old carbonate sources that might give rise to anomalously low levels of ^{14}C. The highest ^{14}C level of 9 pMC gives a minimal age of 19,000 years before present for drillhole 14aSE, though with the limited data we cannot determine whether there has been any contamination from recent carbon sources, such as diffusion of atmospheric CO_2 into the waters. Depth relationships (Figure C2.1) do not suggest this to be occurring (the ^{14}C profile would show a decreasing activity with depth), so we must assume the age to be true.

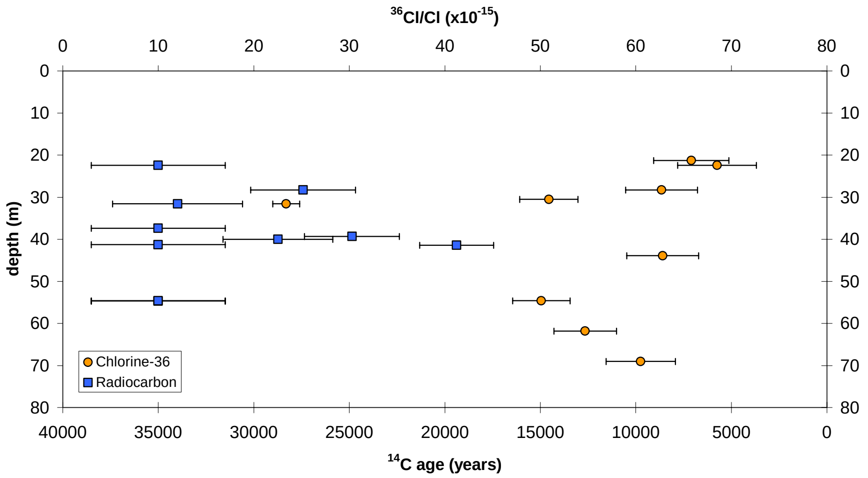


FIGURE C2.1
^{14}C ages and ^{36}Cl /chloride ratios vs depth to watertable

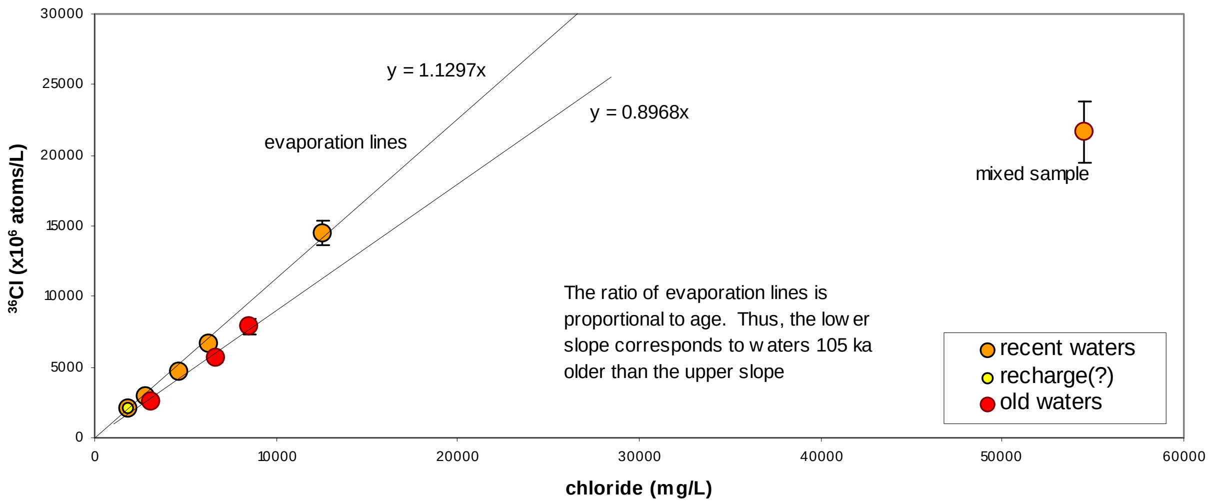


FIGURE C2.2
^{36}Cl concentration vs chloride trends

^{36}Cl has a longer half life than ^{14}C and consequently can give information on salt that is between 50,000 and 1 million years old. Unfortunately, there is currently no easily measurable radio-isotope that covers the range between 30,000 and 50,000 years. Consideration of possible physical processes affecting ^{36}Cl and chloride as rainwater recharges groundwater can help define groups of samples. Thus, in Figure C2.2, evaporation of recharge water results in samples that plot along a straight line away from the origin. Where a number of samples plot on a similar trend, we can assume they are derived from a common original source. Within the errors of the analyses, we can thus define 3 groups of samples from the 9 analysed, including a sample that appears to be a mix of evaporated rainwaters and an older source of salt (drillhole 12SE). This bore also gave an anomalously high yield (3 L/s) from a mineralised fracture zone at 99 m, and appears to tap an older more saline source of groundwater.

It is common practice to equate the uppermost trend to recent recharge. Our measurement sensitivity for ^{36}Cl is such that this can be any water recharged in the past 50,000 years. If we further assume no mixing for the waters lying on the evaporation trends, then the ratio of the 2 lines represents the age difference between the 2 groups. For these samples that equates to 105,000 years.

As for the radiocarbon, there is no apparent relationship of ^{36}Cl with depth (Figure C2.1).

Five samples were analysed for both ^{14}C and ^{36}Cl. Only samples with ^{36}Cl concentrations on the upper evaporation trend gave ^{14}C levels above background, adding further credence to the finite ^{14}C ages for these waters.

The 3 samples that plot on the lower trend are from drillholes 7SW, 45NW and the Pines Well (10 km SW of Site 40a). These all lie east of the major groundwater divide that trends from Andamooka, south to Woomera, then west to Glendambo. It is conceivable that the old chloride may relate to an ancient shoreline of the lakes that surround the region, but this thesis is beyond the scope of this investigation. An alternative explanation is that the old salt is a diffusion product out of low permeability sections of the Simmens Quartzite.

In summary, the radio-isotopes, ^{14}C and ^{36}Cl indicate that groundwater in the region is at least 20,000 years old, with much of it being much older, particularly to the south and east where waters appear to be in excess of 100,000 years old. Within the analytical limits of the measurement techniques, and the inherent variability of radio-isotope concentrations in nature, we cannot be more precise than this.

C2.5 Recharge Processes Indicated by Deviation of the Stable Isotopes $\delta^{18}O$ and δD from the Meteoric Water Line

Oxygen-18 and deuterium data for all bores pumped during stage 1, 2 and 3 drilling are shown in web report Appendix 8. The regional groundwaters have $\delta^{18}O$ values ranging from –6‰ (permil) (Paradise Well, near Site 10a) to –1‰ (12SE) and $\delta^{2}H$ values ranging from –44‰ to –21‰ for the same wells. Figure C2.3 shows a plot of the $\delta^{18}O$ and $\delta^{2}H$ groundwater values and their positions relative to the Adelaide and Alice Springs Meteoric Water Lines. All groundwater samples plot to the right of the meteoric water lines in Figure C2.3, indicating fractionation by evapo-transpiration of infiltrating rainwater prior to recharge of the aquifers. The eight samples from Site 52a are heavier (i.e. more evaporated) than those from 45a and 40a (there was only one sample collected from Site 40a).

Also shown in Figure C2.3 are the isotopic compositions of the long-term monthly amount weighted means for Adelaide and Alice Springs rainfall. Both show increasing depletion in the stable isotopes with rainfall intensity. The intercept of the groundwater evaporation line and the meteoric water lines should define the recharge threshold. According to Figure C2.3, recharge only occurs after amounts of at least 80 mm in a single month for rainfall emanating from the south (Adelaide winter maximum) or for higher intensity events of 100–150 mm in a single month for rainfall emanating from the north (Alice Springs summer maximum). Figures C2.4 and C2.5 respectively show the frequency of rainfall events which exceeded 80 mm in a single month for Andamooka (record 1965–1998) and Woomera (1895–1998). The majority are summer thunderstorm events, and these higher intensity rainfalls appear to be more frequent at Andamooka (11 events over 33 years) compared to Woomera (15 events over 103 years), despite there being no significant difference in average annual rainfall between the two stations. The implication here is that the potential for recharge at Site 45a (closest to Andamooka) is higher than at Sites 52a or 40a. Whether or not this actually occurs depends on the substrate permeability.

C2.6 Summary of Recharge Rates and Groundwater Residence Times

Comparisons of recharge rates estimated by chloride mass balance in the saturated and unsaturated zone are shown in Table C2.1. Also shown are estimated and observed groundwater ages based on residence times in the unsaturated zone under conditions of one-dimensional vertical piston flow-type recharge.

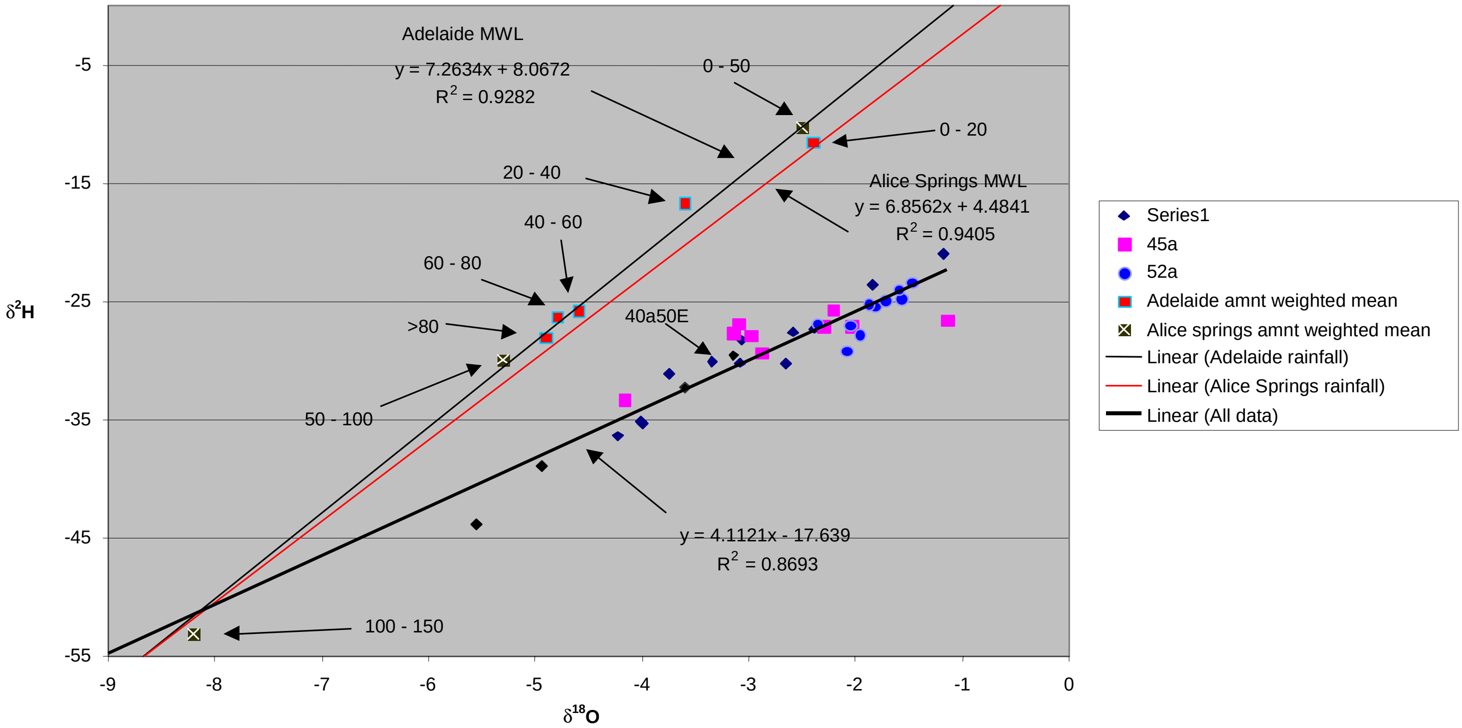


FIGURE C2.3
Oxygen-18 and deuterium values of regional groundwater samples relative to Adelaide and Alice Springs meteoric water lines

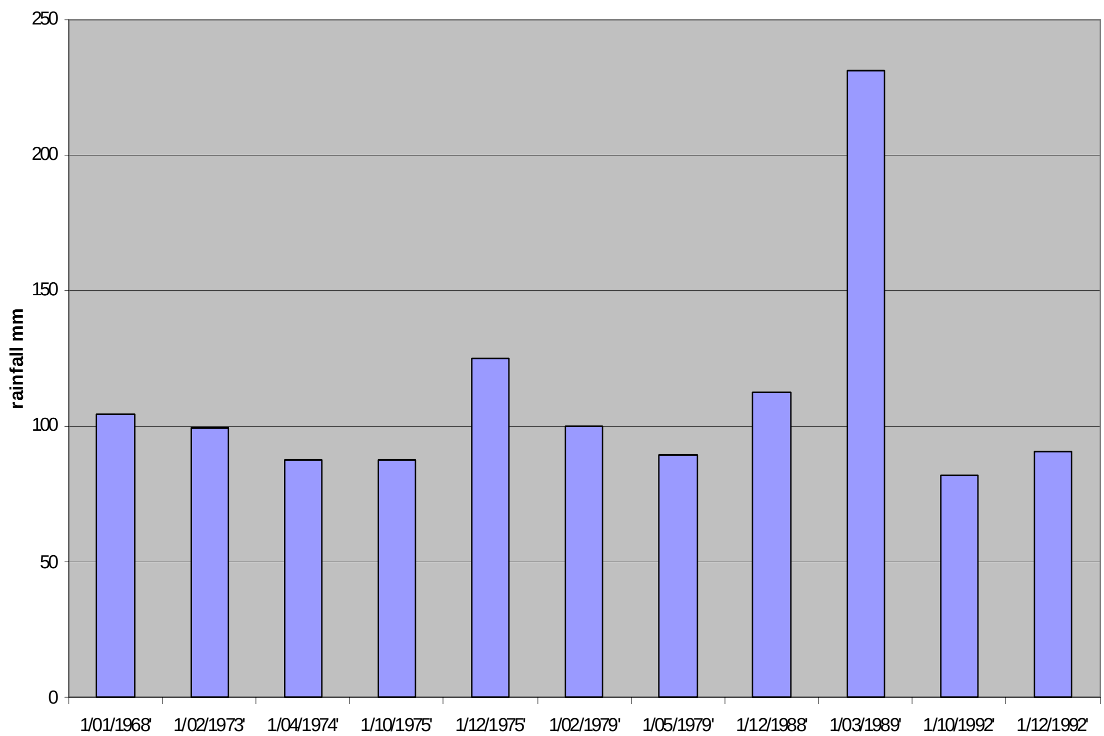


FIGURE C2.4
Andamooka monthly rainfall >80 mm (1965–1998)

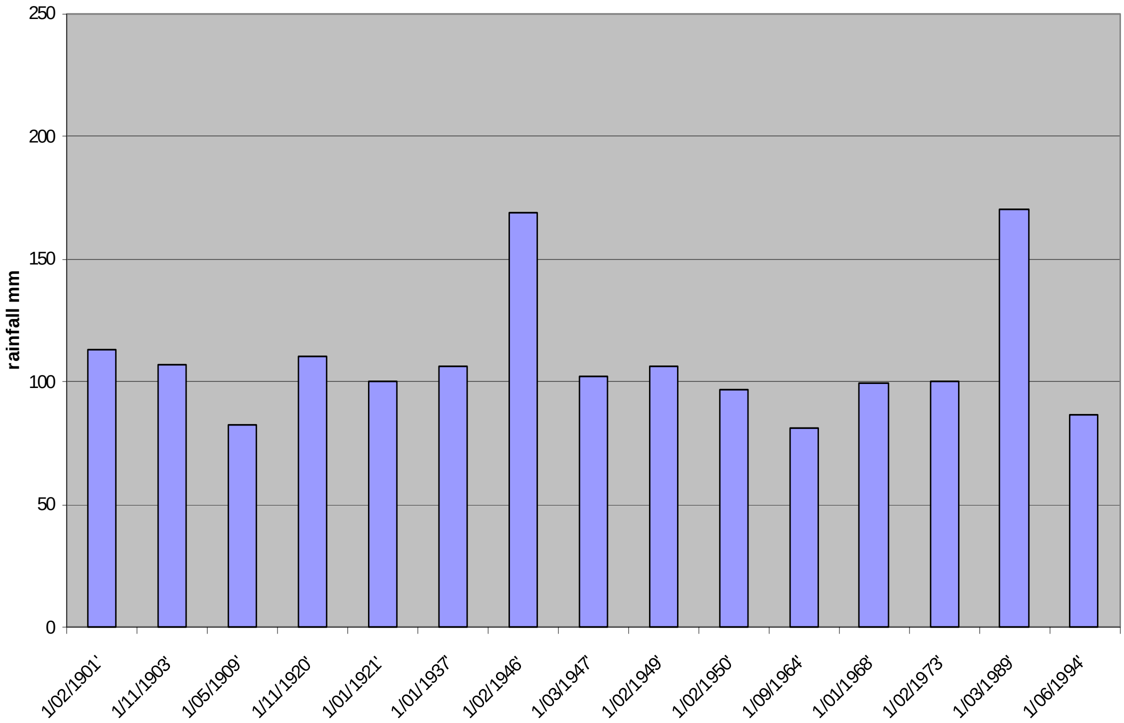


FIGURE C2.5
Woomera monthly rainfall >80 mm (1895–1998)

TABLE C2.1 Recharge rates and groundwater ages/residence times

Method	Site 40a	Site 45a	Site 52a
Recharge rates (mm/year)			
Cl mass balance (sat. zone)	0.06	0.06	0.09
Cl mass balance (unsat. zone)	0.02	0.02–0.17(1)	0.03–0.05
Residence times in unsaturated zone (years)			
Cl mass balance (sat. zone)	11,000	9,000	14,000
Cl mass balance (unsat. zone)	33,000	3,000(1)–27,000	25,000–42,000
^{14}C	n.a.	>30,000	>30,000 (52aSE) 29,000 (52aNW)
^{36}Cl	n.a.	<100,000	n.a.

(1) Probably via preferential flow path

There is a marked discrepancy between the recharge rates estimated by chloride mass balance in the saturated and unsaturated zones. More credibility should be placed on the unsaturated zone analyses, especially for Site 52a. The chloride and moisture vs depth patterns, and the linearity of the cumulative chloride profile support the assumption of piston flow-type recharge at Site 52a. These plots also indicate the presence of a diffusion gradient to a fresher watertable. Therefore, the saturated zone consists of a mixed groundwater system with two end members: (1) a downward piston-type flux with residence times of 25,000–40,000 years in the unsaturated zone, and (2) a lateral throughflow component of lower chlorinity whose residence time in the saturated zone may be as short as 800 years after infiltration (based on a regional groundwater velocity of 7 m/yr in @wc in response to a head drop of 24 m from the groundwater divide 6 km to the SW).

The chloride and moisture vs depth patterns indicate the chloride mass balance technique (for both saturated and unsaturated zones) is strictly not appropriate for recharge estimation at Sites 40a and 45a. Even allowing for experimental error, pore fluids in the tight quartzite layers in @ws appear to be of brinelike composition. These fluids are not in equilibrium with modern groundwater and their age is unknown. It is likely that chloride is diffused into the unsaturated zone from these layers and this violates the assumption of the sole source of chloride being atmospheric input. In addition, the chloride and moisture patterns in drillhole 45aNW strongly suggest the existence of preferential flow paths in @ws, violating the assumption of piston flow. The conceptual model for evolution of groundwater at Sites 40a and 45a is therefore a ternary mixing system, composed of the following end members:

- non-uniform recharge through clay and clayey sandstone bands in @ws at a rate of about 0.02 mm/yr and residence times in the unsaturated zone of the order of 30,000 years
- a lateral throughflow component of lower chlorinity which has probably been recharged locally through preferential flow paths (eg. fractures, porous sandstone bands)
- diffusion of salts from tight sections of quartzite in @ws.

C2.7 References

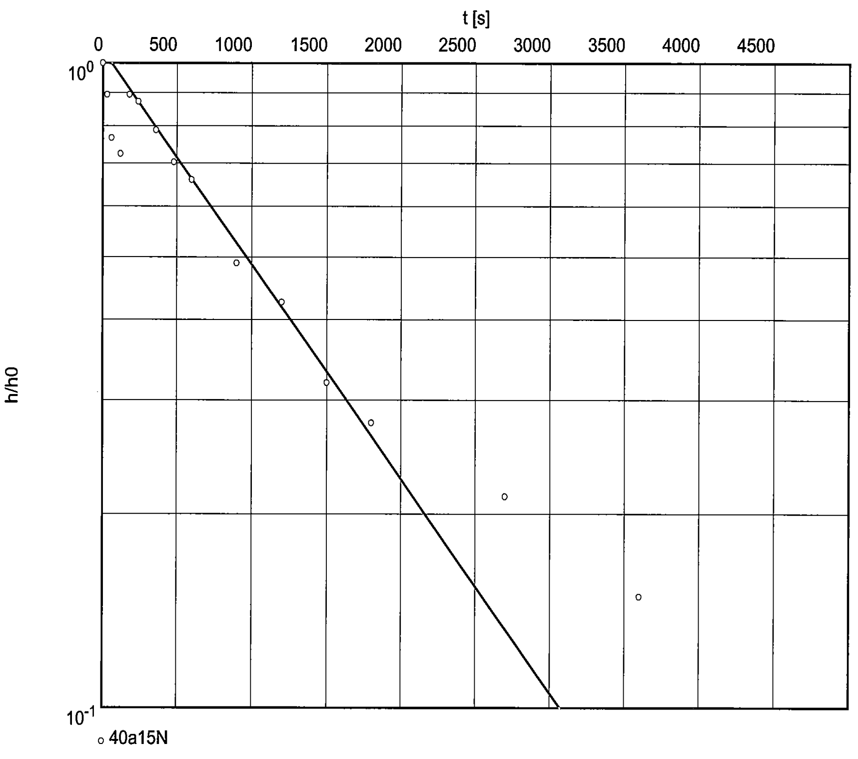
Harries, JR, Kirby, JM, Payne, TE and Smiles, DE. 1998. Technical studies for site selection of a national low-level radioactive waste repository. 4. Vadose zone hydrology and radionuclide retardation. Available at http://www.dest.gov.au/radwaste/index.html.

Appendix C3
Hydraulic Conductivity Tests

The hydraulic conductivity tests reported in this appendix were undertaken by PPK in September 2001 using the Waterloo Hydrogeologic Aquifer Test software package and Hvorslev's method for slug/bail test analysis.

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 1 Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 5	Test conducted on: 11/08/01
40a15N	



Hydraulic conductivity [m/s]: 1.57×10^{-6}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 2	
		Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001

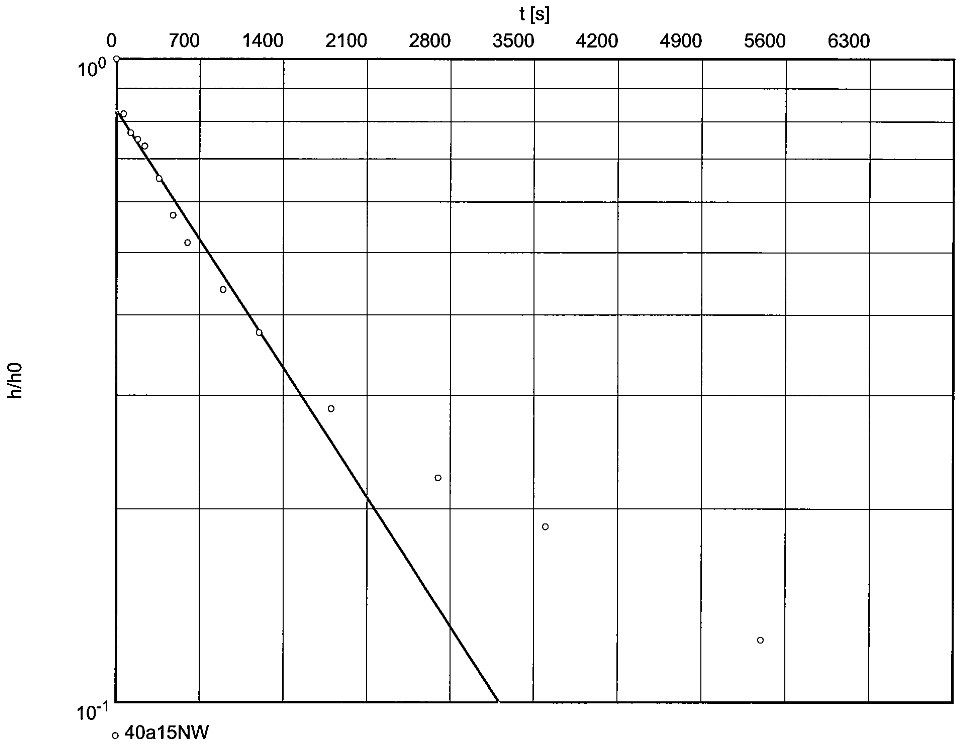
Slug Test No. 5	Test conducted on: 11/08/01
40a15N	40a15N

Static water level: 66.130 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	66.600	0.470	
2	30	66.550	0.420	
3	60	66.490	0.360	
4	120	66.470	0.340	
5	180	66.550	0.420	
6	240	66.540	0.410	
7	360	66.500	0.370	
8	480	66.460	0.330	
9	600	66.440	0.310	
10	900	66.360	0.230	
11	1200	66.330	0.200	
12	1500	66.280	0.150	
13	1800	66.260	0.130	
14	2700	66.230	0.100	
15	3600	66.200	0.070	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 3 Project: Radwaste EIS Evaluated by: MLP / Date: 24.09.2001

Slug Test No. 8	Test conducted on: 11/08/01
40a15NW	



Hydraulic conductivity [m/s]: 8.23×10^{-7}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 4	
		Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001

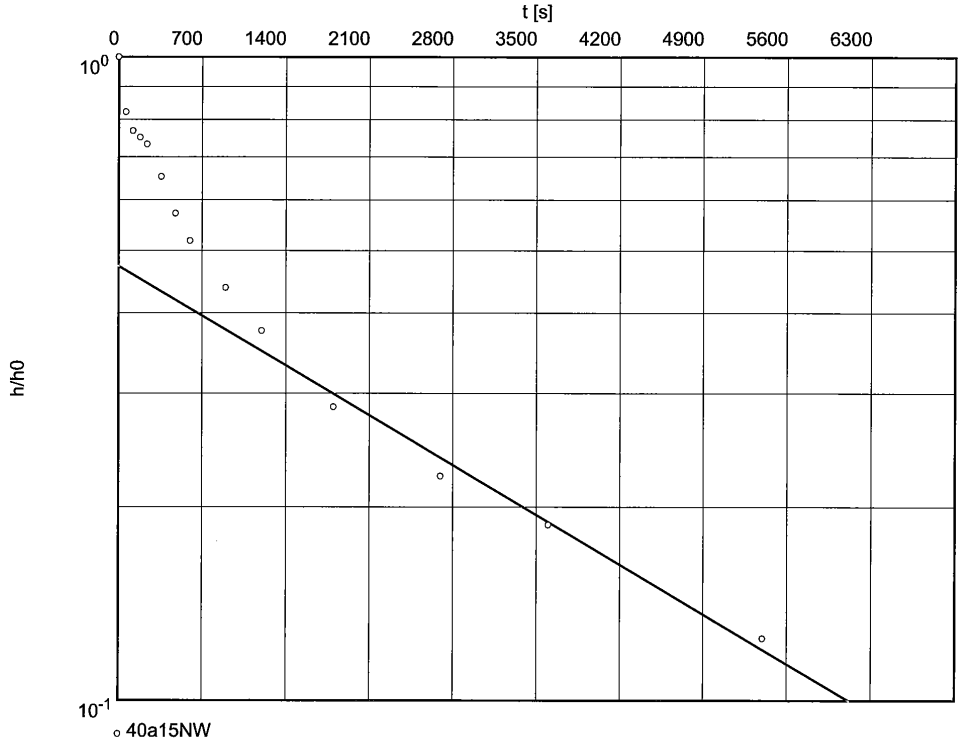
Slug Test No. 8	Test conducted on: 11/08/01
40a15NW	40a15NW

Static water level: 65.320 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	64.200	-1.120	
2	60	64.400	-0.920	
3	120	64.460	-0.860	
4	180	64.480	-0.840	
5	240	64.500	-0.820	
6	360	64.590	-0.730	
7	480	64.680	-0.640	
8	600	64.740	-0.580	
9	900	64.830	-0.490	
10	1200	64.900	-0.420	
11	1800	65.000	-0.320	
12	2700	65.070	-0.250	
13	3600	65.110	-0.210	
14	5400	65.180	-0.140	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 5 Project: Radwaste EIS Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 8	Test conducted on: 11/08/01
40a15NW	



Hydraulic conductivity [m/s]: 3.17×10^{-7}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 6 Project: Radwaste EIS Evaluated by: MLP · Date: 24.09.2001

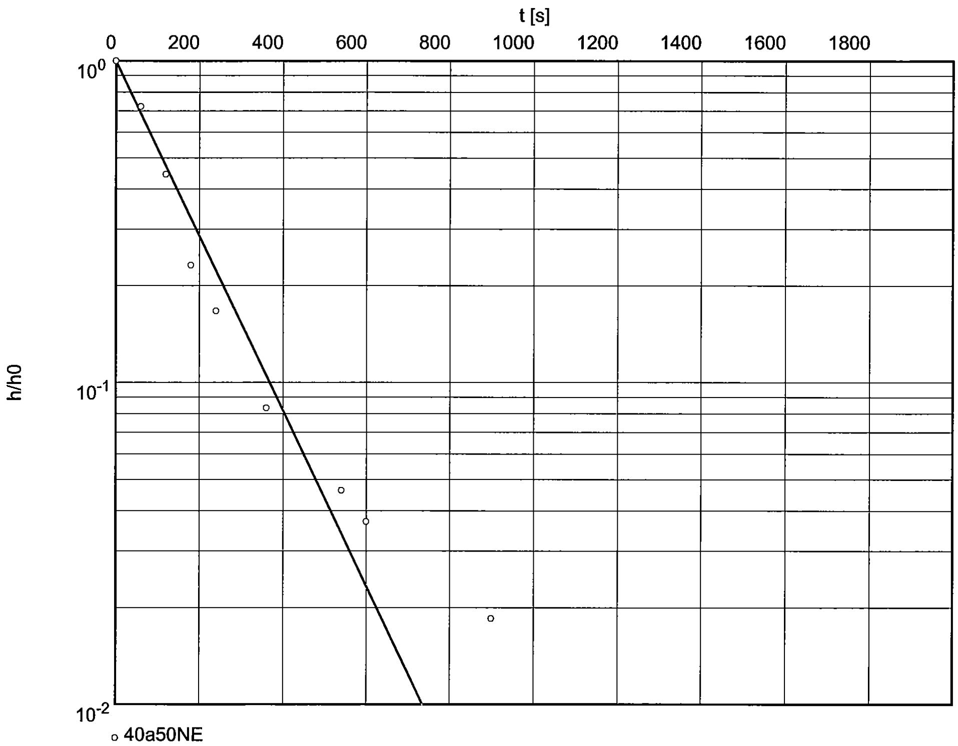
Slug Test No. 8	Test conducted on: 11/08/01
40a15NW	40a15NW

Static water level: 65.320 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	64.200	-1.120	
2	60	64.400	-0.920	
3	120	64.460	-0.860	
4	180	64.480	-0.840	
5	240	64.500	-0.820	
6	360	64.590	-0.730	
7	480	64.680	-0.640	
8	600	64.740	-0.580	
9	900	64.830	-0.490	
10	1200	64.900	-0.420	
11	1800	65.000	-0.320	
12	2700	65.070	-0.250	
13	3600	65.110	-0.210	
14	5400	65.180	-0.140	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 7 Project: Radwaste EIS Evaluated by: MLP — Date: 24.09.2001

Slug Test No. 7	Test conducted on: 11/08/01
40a50NE	



Hydraulic conductivity [m/s]: 5.74×10^{-6}

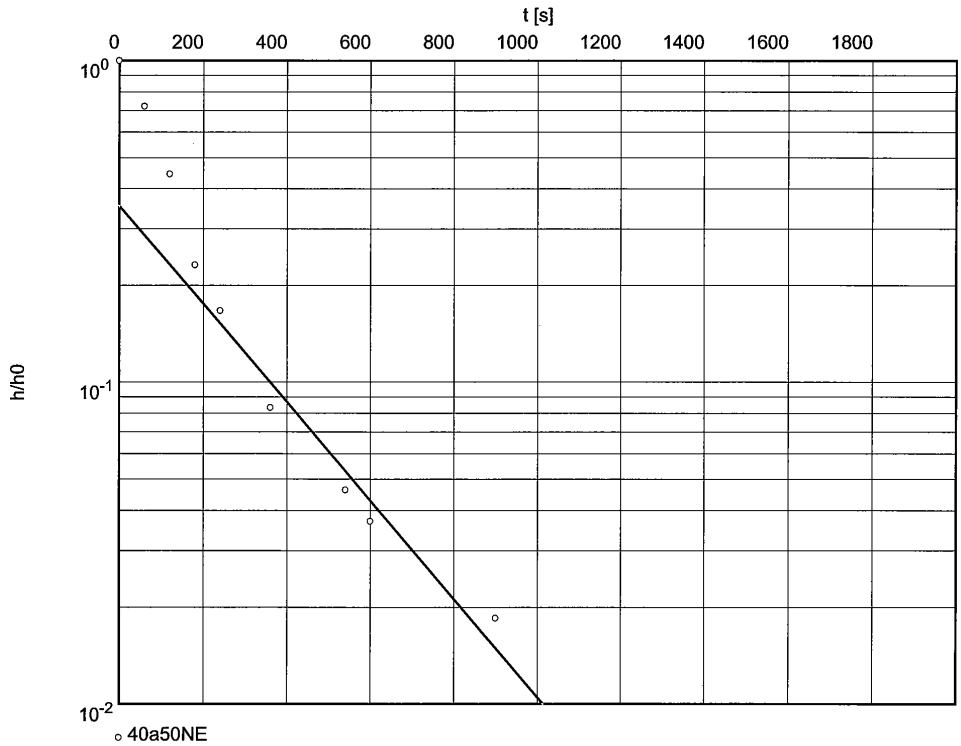
Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 8 Project: Radwaste EIS Evaluated by: MLP Date: 24.09.2001

Slug Test No. 7	Test conducted on: 11/08/01
40a50NE	40a50NE

Static water level: 67.080 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	66.000	-1.080	
2	60	66.300	-0.780	
3	120	66.600	-0.480	
4	180	66.830	-0.250	
5	240	66.900	-0.180	
6	360	66.990	-0.090	
7	540	67.030	-0.050	
8	600	67.040	-0.040	
9	900	67.060	-0.020	
10	1500	67.080	0.000	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 9 Project: Radwaste EIS Evaluated by: MLP	Date: 24.09.2001
Slug Test No. 7		Test conducted on: 11/08/01	
40a50NE			



Hydraulic conductivity [m/s]: 3.22×10^{-6}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 10 Project: Radwaste EIS Evaluated by: MLP · Date: 24.09.2001

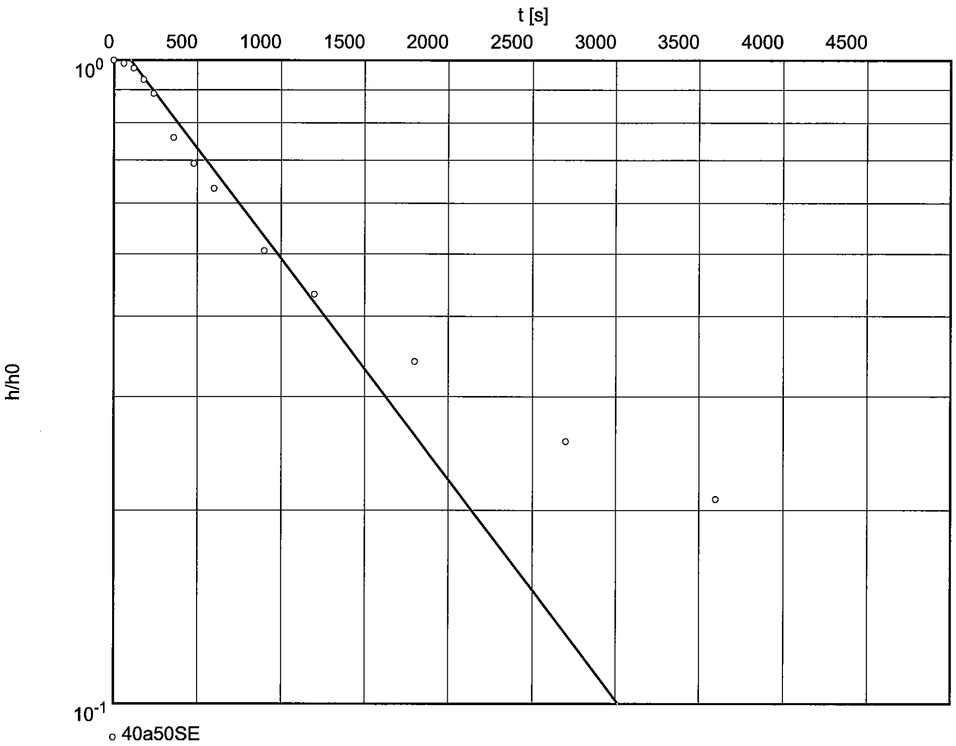
Slug Test No. 7	Test conducted on: 11/08/01
40a50NE	40a50NE

Static water level: 67.080 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	66.000	-1.080	
2	60	66.300	-0.780	
3	120	66.600	-0.480	
4	180	66.830	-0.250	
5	240	66.900	-0.180	
6	360	66.990	-0.090	
7	540	67.030	-0.050	
8	600	67.040	-0.040	
9	900	67.060	-0.020	
10	1500	67.080	0.000	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 11 Project: Radwaste EIS Evaluated by: MLP Date: 24.09.2001

Slug Test No. 6	Test conducted on: 11/08/01
40a50SE	



Hydraulic conductivity [m/s]: 4.85×10^{-7}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 12 Project: Radwaste EIS Evaluated by: MLP Date: 24.09.2001

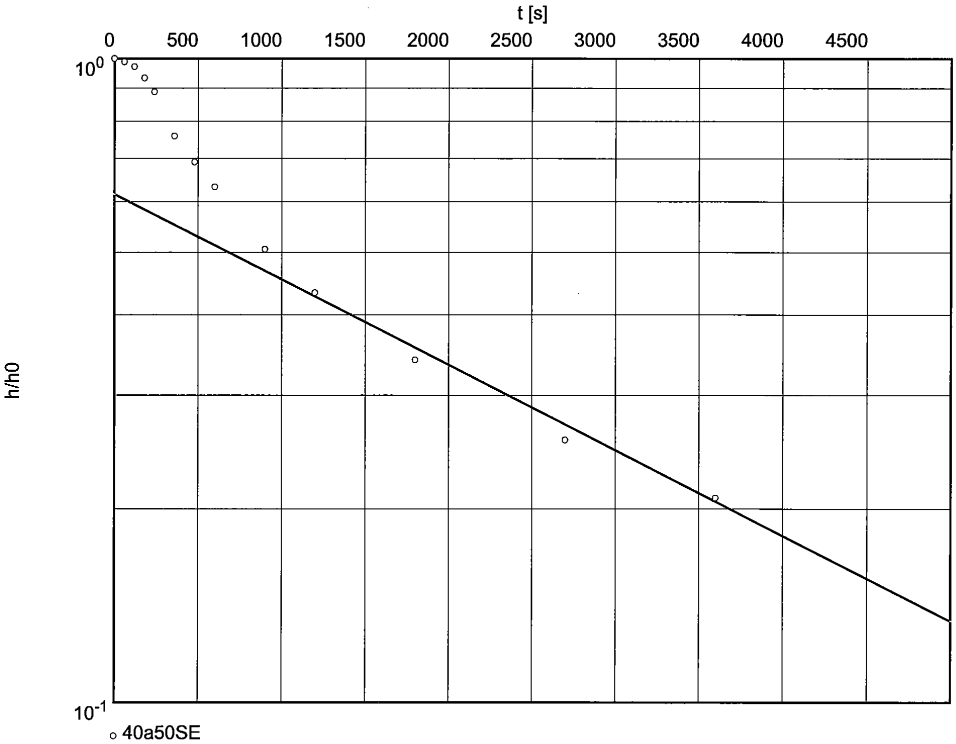
Slug Test No. 6	Test conducted on: 11/08/01
40a50SE	40a50SE

Static water level: 67.980 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	66.200	-1.780	
2	60	66.220	-1.760	
3	120	66.250	-1.730	
4	180	66.320	-1.660	
5	240	66.400	-1.580	
6	360	66.630	-1.350	
7	480	66.750	-1.230	
8	600	66.855	-1.125	
9	900	67.080	-0.900	
10	1200	67.210	-0.770	
11	1800	67.375	-0.605	
12	2700	67.525	-0.455	
13	3600	67.610	-0.370	
14	5400	67.700	-0.280	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 13	
		Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 6	Test conducted on: 11/08/01
40a50SE	



Hydraulic conductivity [m/s]: 1.87×10^{-7}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 14 Project: Radwaste EIS Evaluated by: MLP	Date: 24.09.2001

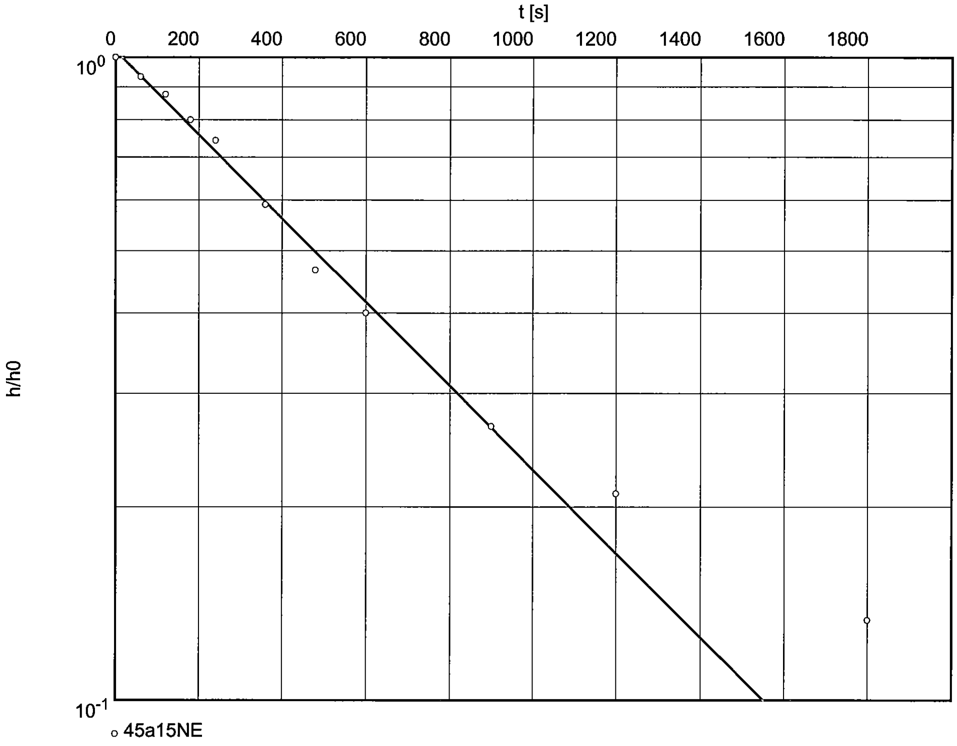
Slug Test No. 6	Test conducted on: 11/08/01
40a50SE	40a50SE

Static water level: 67.980 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	66.200	-1.780	
2	60	66.220	-1.760	
3	120	66.250	-1.730	
4	180	66.320	-1.660	
5	240	66.400	-1.580	
6	360	66.630	-1.350	
7	480	66.750	-1.230	
8	600	66.855	-1.125	
9	900	67.080	-0.900	
10	1200	67.210	-0.770	
11	1800	67.375	-0.605	
12	2700	67.525	-0.455	
13	3600	67.610	-0.370	
14	5400	67.700	-0.280	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 15 Project: Radwaste EIS Evaluated by: MLP / Date: 24.09.2001

Slug Test No. 4	Test conducted on: 10/08/01
45a15NE	



Hydraulic conductivity [m/s]: 4.23×10^{-7}

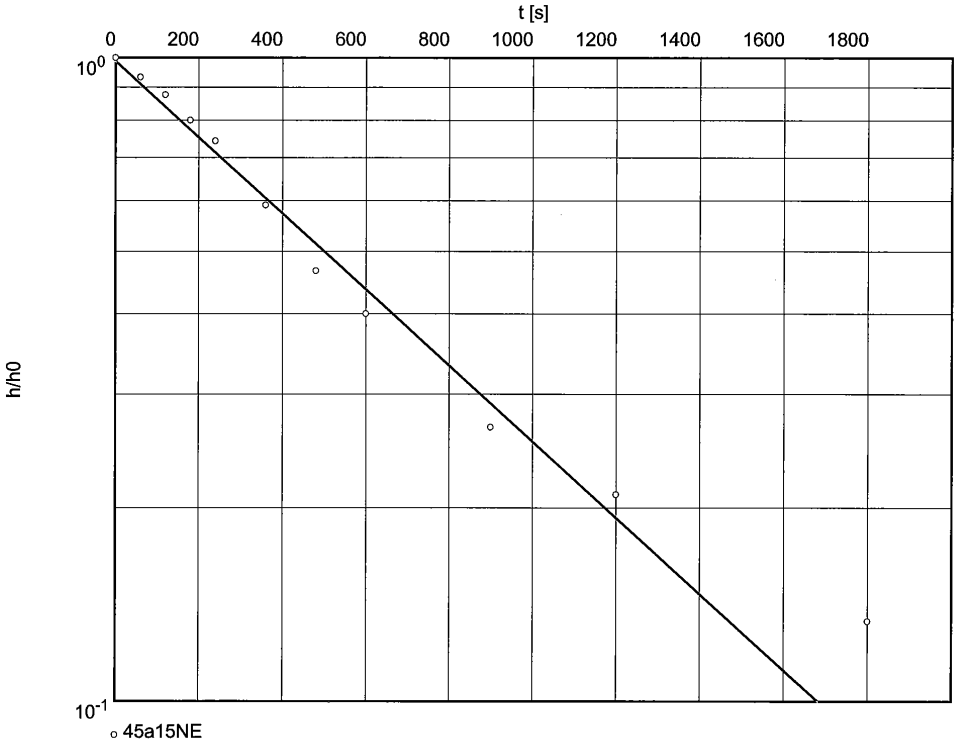
Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 16 Project: Radwaste EIS Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 4	Test conducted on: 10/08/01
45a15NE	45a15NE
Static water level: 53.850 m below datum	

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	52.800	-1.050	
2	60	52.870	-0.980	
3	120	52.930	-0.920	
4	180	53.010	-0.840	
5	240	53.070	-0.780	
6	360	53.230	-0.620	
7	480	53.360	-0.490	
8	600	53.430	-0.420	
9	900	53.570	-0.280	
10	1200	53.630	-0.220	
11	1800	53.710	-0.140	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 17 Project: Radwaste EIS Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 4	Test conducted on: 10/08/01
45a15NE	



Hydraulic conductivity [m/s]: 3.84×10^{-7}

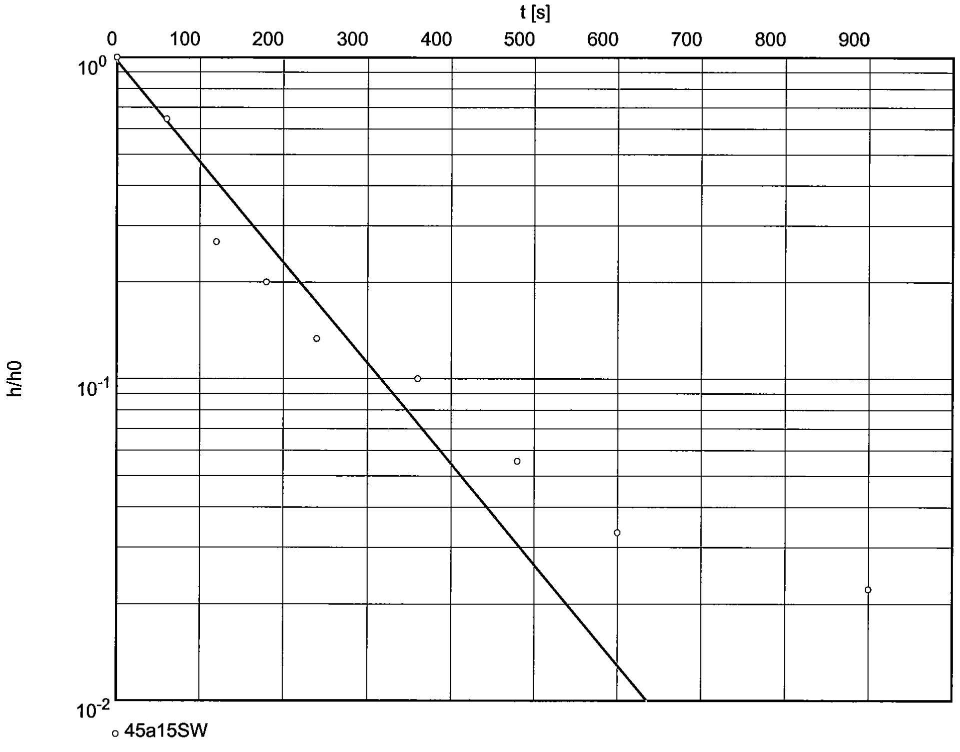
Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 18 Project: Radwaste EIS Evaluated by: MLP / Date: 24.09.2001

Slug Test No. 4	Test conducted on: 10/08/01
45a15NE	45a15NE

Static water level: 53.850 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	52.800	-1.050	
2	60	52.870	-0.980	
3	120	52.930	-0.920	
4	180	53.010	-0.840	
5	240	53.070	-0.780	
6	360	53.230	-0.620	
7	480	53.360	-0.490	
8	600	53.430	-0.420	
9	900	53.570	-0.280	
10	1200	53.630	-0.220	
11	1800	53.710	-0.140	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 19 Project: Radwaste EIS Evaluated by: MLP	 Date: 24.09.2001
Slug Test No. 1		Test conducted on: 10/08/01	
45a15SW			



Hydraulic conductivity [m/s]: 3.03×10^{-6}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 20 Project: Radwaste EIS Evaluated by: MLP / Date: 24.09.2001

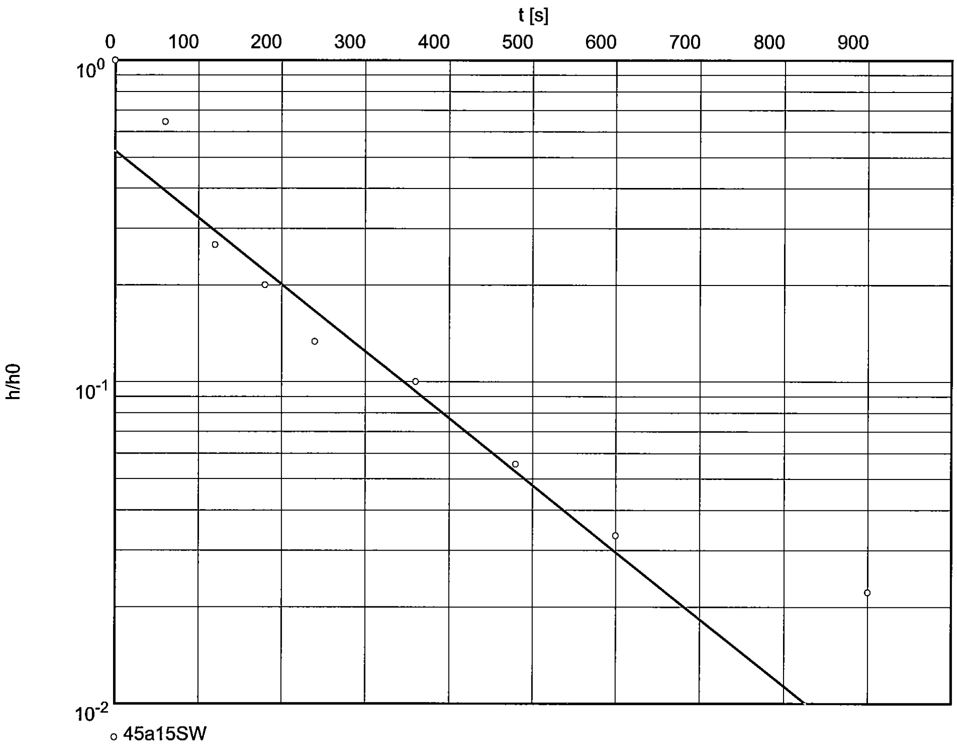
Slug Test No. 1	Test conducted on: 10/08/01
45a15SW	45a15SW

Static water level: 53.900 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	53.000	-0.900	
2	60	53.320	-0.580	
3	120	53.660	-0.240	
4	180	53.720	-0.180	
5	240	53.780	-0.120	
6	360	53.810	-0.090	
7	480	53.850	-0.050	
8	600	53.870	-0.030	
9	900	53.880	-0.020	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 21 Project: Radwaste EIS Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 1	Test conducted on: 10/08/01
45a15SW	



Hydraulic conductivity [m/s]: 2.01×10^{-6}

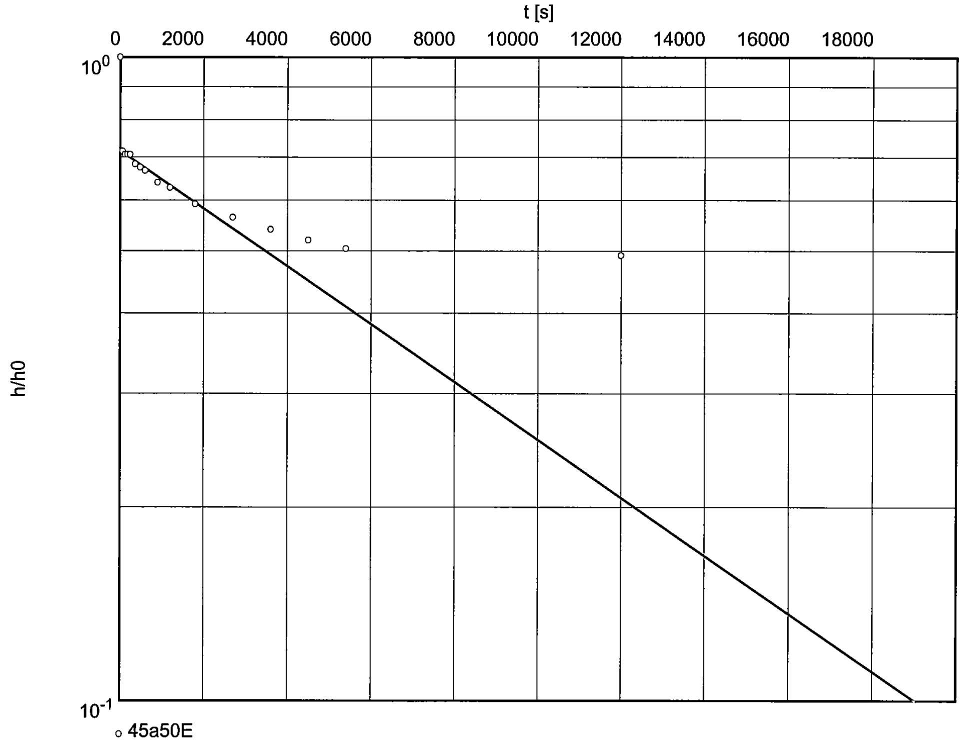
Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 22 Project: Radwaste EIS Evaluated by: MLP / Date: 24.09.2001

Slug Test No. 1	Test conducted on: 10/08/01
45a15SW	45a15SW

Static water level: 53.900 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	53.000	-0.900	
2	60	53.320	-0.580	
3	120	53.660	-0.240	
4	180	53.720	-0.180	
5	240	53.780	-0.120	
6	360	53.810	-0.090	
7	480	53.850	-0.050	
8	600	53.870	-0.030	
9	900	53.880	-0.020	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 23 Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001
Slug Test No. 2		Test conducted on: 10/08/01	
45a50E			



Hydraulic conductivity [m/s]: 2.83×10^{-8}

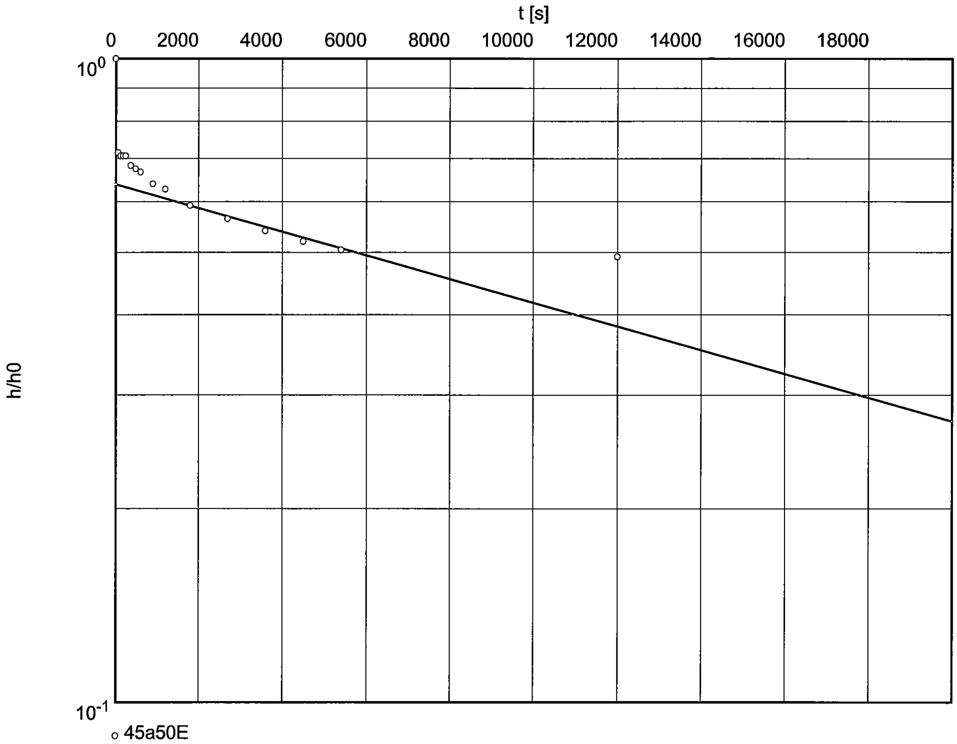
Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 24	
		Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 2	Test conducted on: 10/08/01
45a50E	45a50E

Static water level: 54.160 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	52.900	-1.260	
2	60	53.260	-0.900	
3	120	53.270	-0.890	
4	180	53.270	-0.890	
5	240	53.270	-0.890	
6	360	53.300	-0.860	
7	480	53.310	-0.850	
8	600	53.320	-0.840	
9	900	53.355	-0.805	
10	1200	53.370	-0.790	
11	1800	53.415	-0.745	
12	2700	53.450	-0.710	
13	3600	53.480	-0.680	
14	4500	53.505	-0.655	
15	5400	53.525	-0.635	
16	12000	53.540	-0.620	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 25 Project: Radwaste EIS Evaluated by: MLP	Date: 24.09.2001
Slug Test No. 2		Test conducted on: 10/08/01	
45a50E			



Hydraulic conductivity [m/s]: 1.16×10^{-8}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 26	
		Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 2	Test conducted on: 10/08/01
45a50E	45a50E

Static water level: 54.160 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	52.900	-1.260	
2	60	53.260	-0.900	
3	120	53.270	-0.890	
4	180	53.270	-0.890	
5	240	53.270	-0.890	
6	360	53.300	-0.860	
7	480	53.310	-0.850	
8	600	53.320	-0.840	
9	900	53.355	-0.805	
10	1200	53.370	-0.790	
11	1800	53.415	-0.745	
12	2700	53.450	-0.710	
13	3600	53.480	-0.680	
14	4500	53.505	-0.655	
15	5400	53.525	-0.635	
16	12000	53.540	-0.620	

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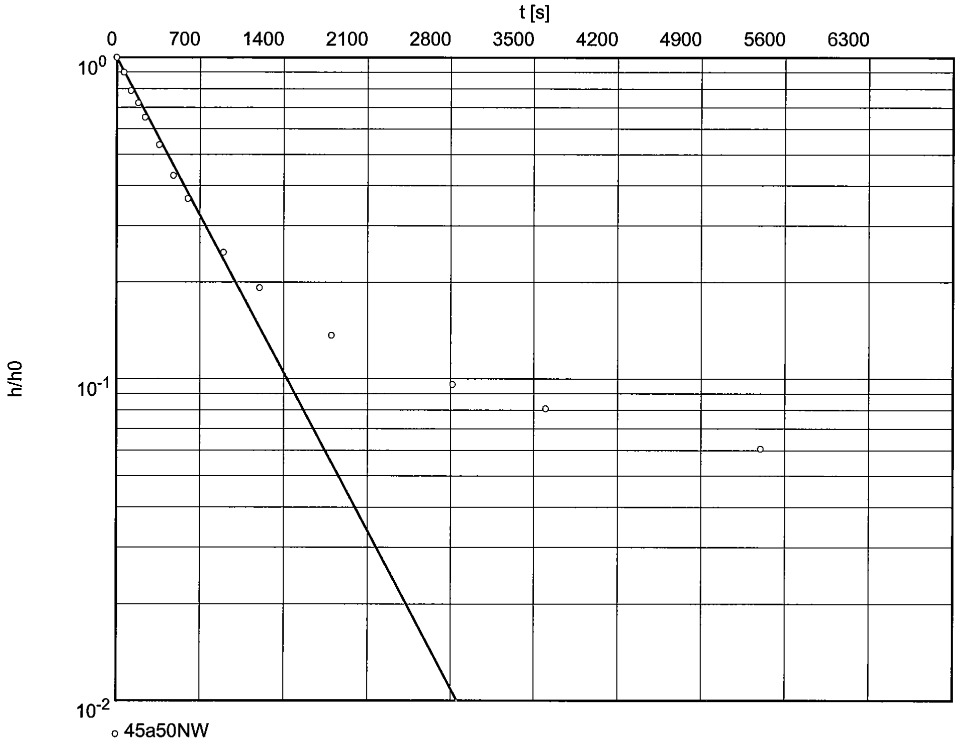
Slug Test No. 3	Test conducted on: 10/08/01
45a50NW	



Hydraulic conductivity [m/s]: 3.05×10^{-7}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 28 Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 3	Test conducted on: 10/08/01
45a50NW	45a50NW

Static water level: 51.180 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	49.200	-1.980	
2	60	49.400	-1.780	
3	120	49.620	-1.560	
4	180	49.750	-1.430	
5	240	49.890	-1.290	
6	360	50.120	-1.060	
7	480	50.330	-0.850	
8	600	50.460	-0.720	
9	900	50.690	-0.490	
10	1200	50.800	-0.380	
11	1800	50.910	-0.270	
12	2820	50.990	-0.190	
13	3600	51.020	-0.160	
14	5400	51.060	-0.120	

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		Project: Radwaste EIS	
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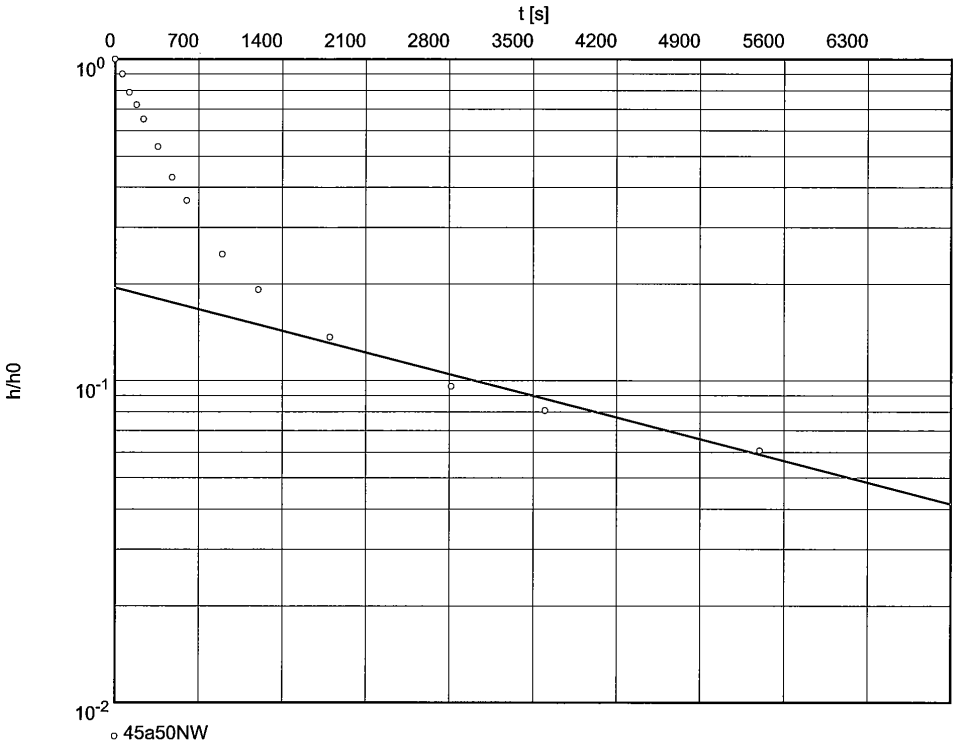
Slug Test No. 3	Test conducted on: 10/08/01
45a50NW	



Hydraulic conductivity [m/s]: 4.19×10^{-8}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 30 Project: Radwaste EIS Evaluated by: MLP — Date: 24.09.2001

Slug Test No. 3	Test conducted on: 10/08/01
45a50NW	45a50NW

Static water level: 51.180 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	49.200	-1.980	
2	60	49.400	-1.780	
3	120	49.620	-1.560	
4	180	49.750	-1.430	
5	240	49.890	-1.290	
6	360	50.120	-1.060	
7	480	50.330	-0.850	
8	600	50.460	-0.720	
9	900	50.690	-0.490	
10	1200	50.800	-0.380	
11	1800	50.910	-0.270	
12	2820	50.990	-0.190	
13	3600	51.020	-0.160	
14	5400	51.060	-0.120	

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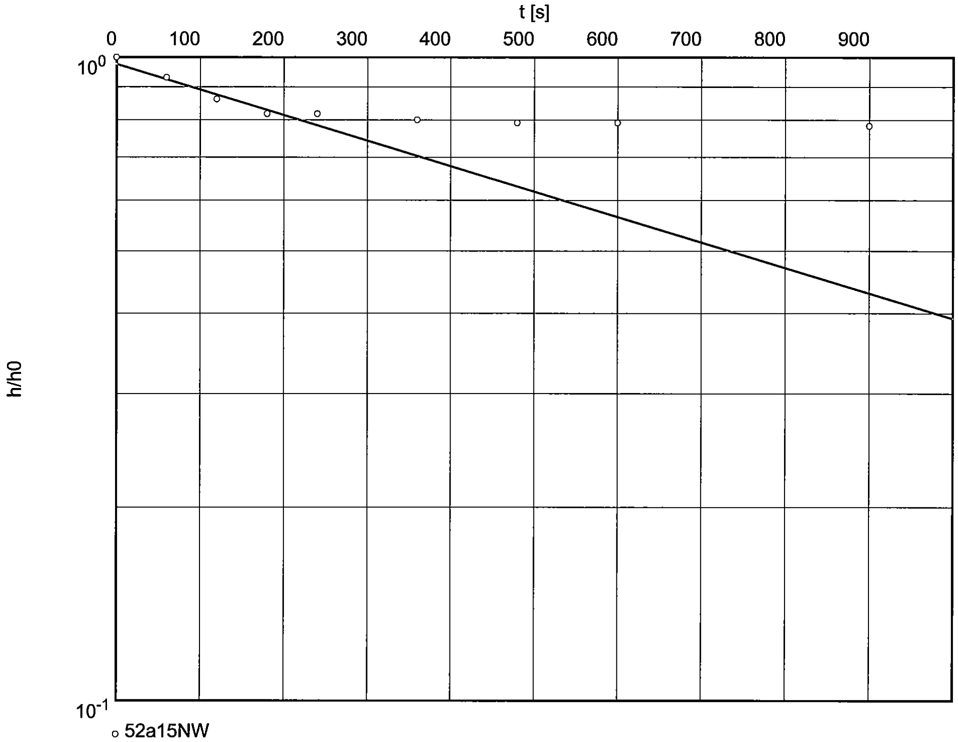
Slug Test No. 9	Test conducted on: 9/08/01
52a15NW	



Hydraulic conductivity [m/s]: 1.96×10^{-7}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 32	
		Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 9	Test conducted on: 9/08/01
52a15NW	52a15NW

Static water level: 38.830 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	39.980	1.150	
2	60	39.900	1.070	
3	120	39.820	0.990	
4	180	39.770	0.940	
5	240	39.770	0.940	
6	360	39.750	0.920	
7	480	39.740	0.910	
8	600	39.740	0.910	
9	900	39.730	0.900	

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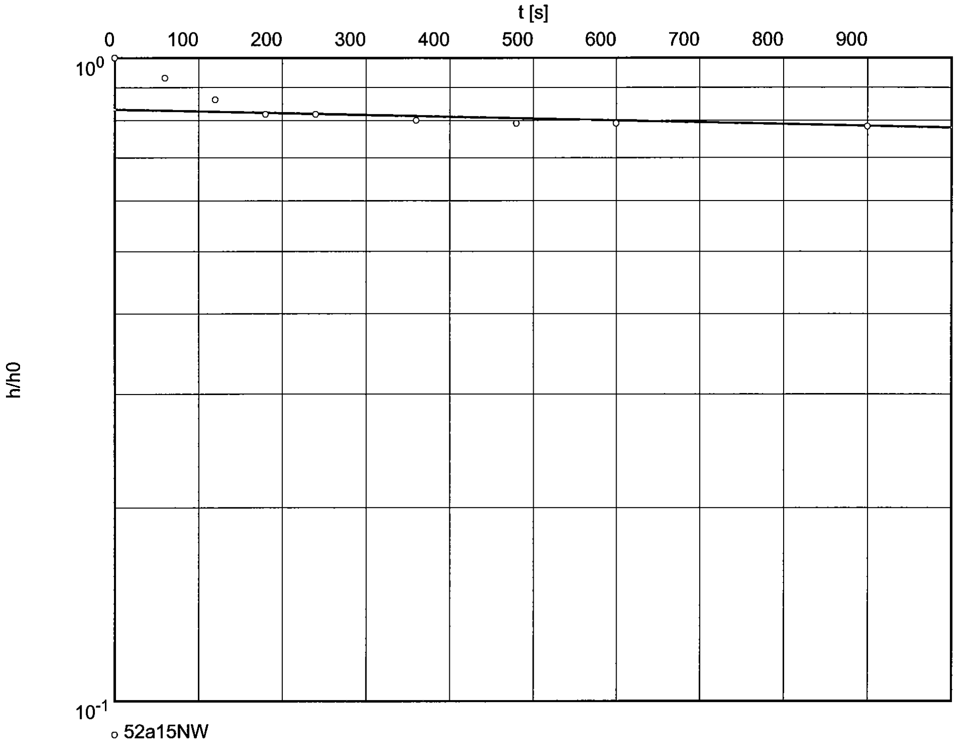
Slug Test No. 9	Test conducted on: 9/08/01
52a15NW	



Hydraulic conductivity [m/s]: 1.39×10^{-8}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 34 Project: Radwaste EIS Evaluated by: MLP Date: 24.09.2001

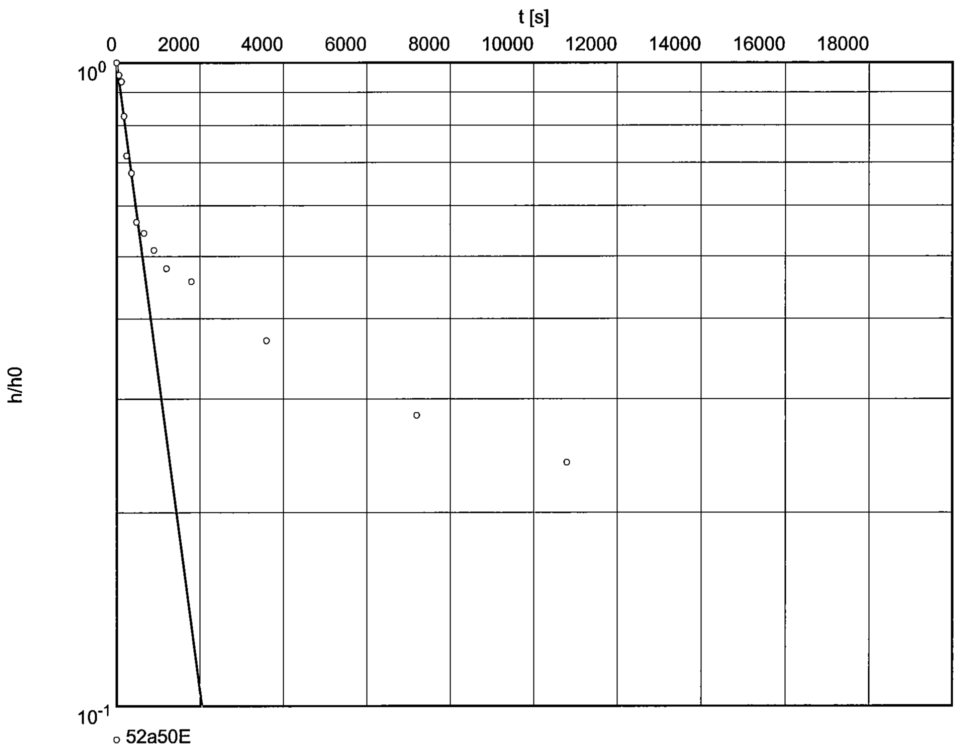
Slug Test No. 9	Test conducted on: 9/08/01
52a15NW	52a15NW

Static water level: 38.830 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	39.980	1.150	
2	60	39.900	1.070	
3	120	39.820	0.990	
4	180	39.770	0.940	
5	240	39.770	0.940	
6	360	39.750	0.920	
7	480	39.740	0.910	
8	600	39.740	0.910	
9	900	39.730	0.900	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 35 Project: Radwaste EIS Evaluated by: MLP · Date: 24.09.2001

Slug Test No. 10	Test conducted on: 9/08/01
52a50E	



Hydraulic conductivity [m/s]: 3.50×10^{-7}

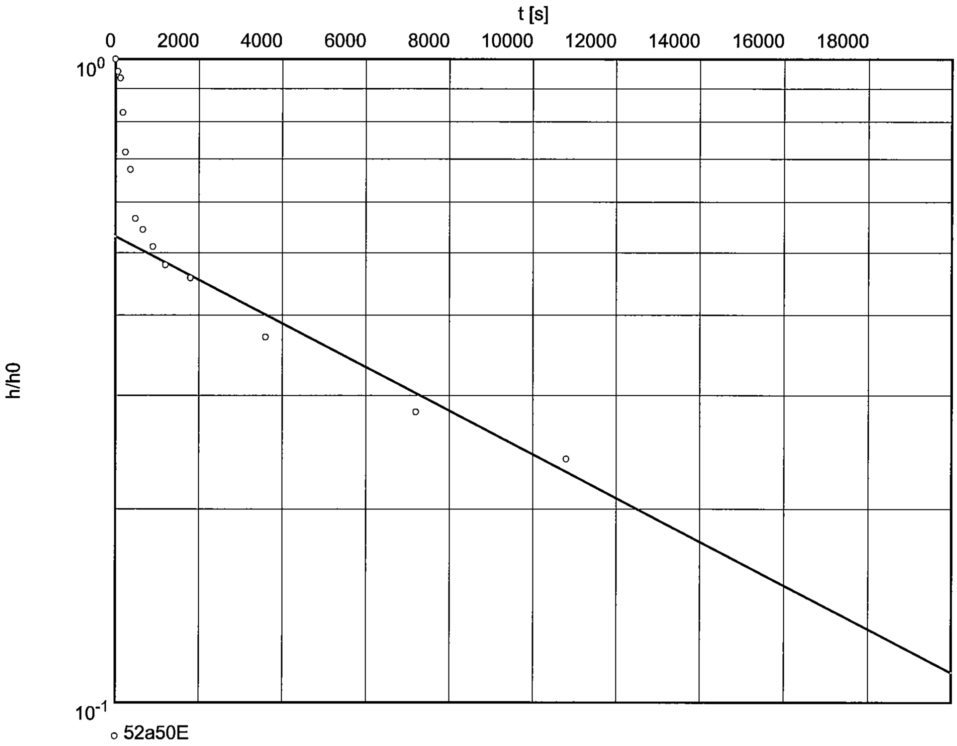
Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 36 Project: Radwaste EIS Evaluated by: MLP Date: 24.09.2001

Slug Test No. 10	Test conducted on: 9/08/01
52a50E	52a50E

Static water level: 42.170 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	42.630	0.460	
2	60	42.610	0.440	
3	120	42.600	0.430	
4	180	42.550	0.380	
5	240	42.500	0.330	
6	360	42.480	0.310	
7	480	42.430	0.260	
8	660	42.420	0.250	
9	900	42.405	0.235	
10	1200	42.390	0.220	
11	1800	42.380	0.210	
12	3600	42.340	0.170	
13	7200	42.300	0.130	
14	10800	42.280	0.110	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 37 Project: Radwaste EIS Evaluated by: MLP	Date: 24.09.2001
Slug Test No. 10		Test conducted on: 9/08/01	
52a50E			



Hydraulic conductivity [m/s]: 2.44×10^{-8}

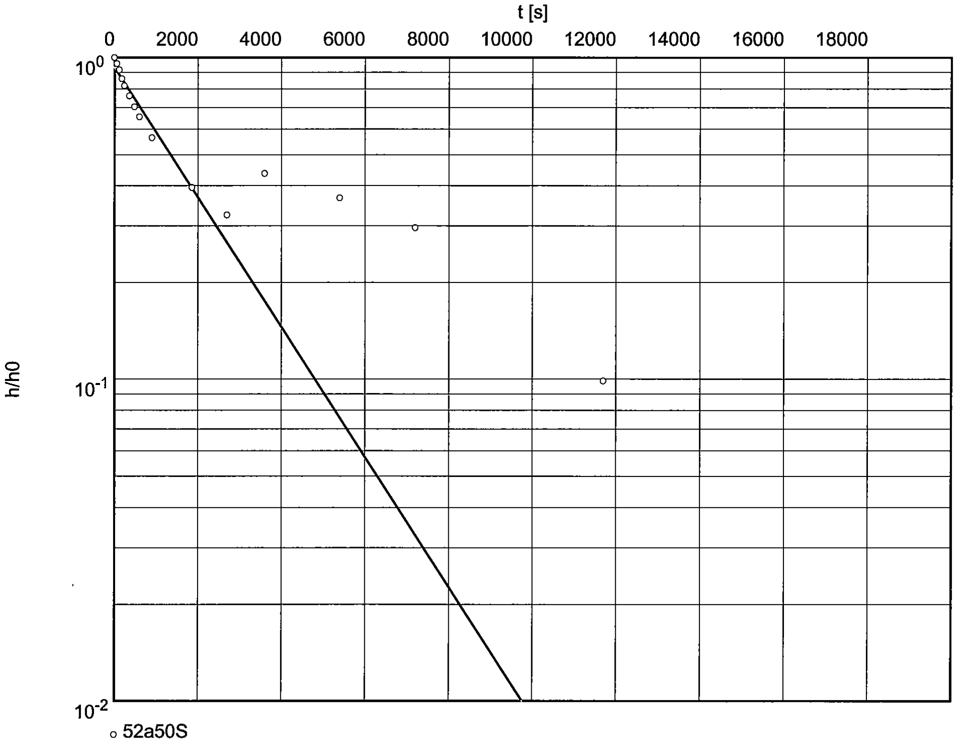
Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 38 Project: Radwaste EIS	
		Evaluated by: MLP	Date: 24.09.2001

Slug Test No. 10	Test conducted on: 9/08/01
52a50E	52a50E

Static water level: 42.170 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	42.630	0.460	
2	60	42.610	0.440	
3	120	42.600	0.430	
4	180	42.550	0.380	
5	240	42.500	0.330	
6	360	42.480	0.310	
7	480	42.430	0.260	
8	660	42.420	0.250	
9	900	42.405	0.235	
10	1200	42.390	0.220	
11	1800	42.380	0.210	
12	3600	42.340	0.170	
13	7200	42.300	0.130	
14	10800	42.280	0.110	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 39 Project: Radwaste EIS Evaluated by: MLP	Date: 24.09.2001
Slug Test No. 12		Test conducted on: 9/08/01	
52a50S			



Hydraulic conductivity [m/s]: 9.36×10^{-8}

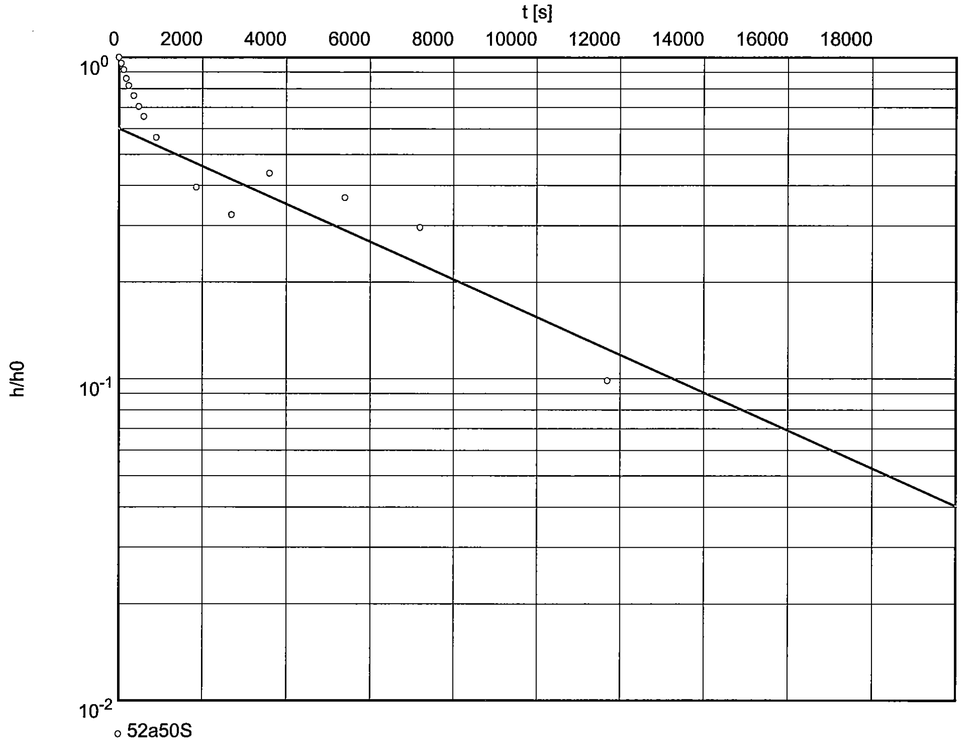
Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 40 Project: Radwaste EIS Evaluated by: MLP Date: 24.09.2001

Slug Test No. 12	Test conducted on: 9/08/01
52a50S	52a50S

Static water level: 42.640 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	43.350	0.710	
2	60	43.320	0.680	
3	120	43.290	0.650	
4	180	43.250	0.610	
5	240	43.220	0.580	
6	360	43.180	0.540	
7	480	43.140	0.500	
8	600	43.105	0.465	
9	900	43.040	0.400	
10	1860	42.920	0.280	
11	2700	42.870	0.230	
12	3600	42.950	0.310	
13	5400	42.900	0.260	
14	7200	42.850	0.210	
15	11700	42.710	0.070	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 41 Project: Radwaste EIS Evaluated by: MLP — Date: 24.09.2001
Slug Test No. 12	Test conducted on: 9/08/01	
52a50S		



Hydraulic conductivity [m/s]: 2.72×10^{-8}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 42 Project: Radwaste EIS Evaluated by: MLP — Date: 24.09.2001

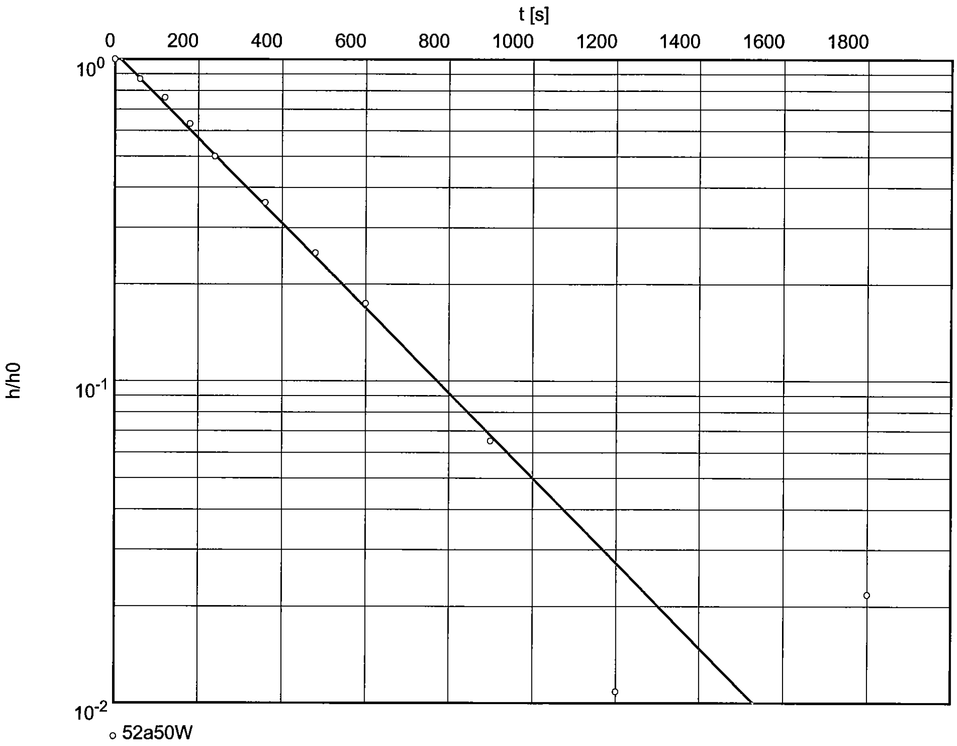
Slug Test No. 12	Test conducted on: 9/08/01
52a50S	52a50S

Static water level: 42.640 m below datum

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	43.350	0.710	
2	60	43.320	0.680	
3	120	43.290	0.650	
4	180	43.250	0.610	
5	240	43.220	0.580	
6	360	43.180	0.540	
7	480	43.140	0.500	
8	600	43.105	0.465	
9	900	43.040	0.400	
10	1860	42.920	0.280	
11	2700	42.870	0.230	
12	3600	42.950	0.310	
13	5400	42.900	0.260	
14	7200	42.850	0.210	
15	11700	42.710	0.070	

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 43 Project: Radwaste EIS Evaluated by: MLP / Date: 24.09.2001

Slug Test No. 11	Test conducted on: 9/08/01
52a50W	



Hydraulic conductivity [m/s]: 9.87×10^{-7}

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	slug/bail test analysis HVORSLEV's method	Page 44
		Project: Radwaste EIS
		Evaluated by: MLP / Date: 24.09.2001

Slug Test No. 11	Test conducted on: 9/08/01
52a50W	52a50W
Static water level: 41.660 m below datum	

	Pumping test duration [s]	Water level [m]	Change in Waterlevel [m]	
1	0	42.120	0.460	
2	60	42.060	0.400	
3	120	42.010	0.350	
4	180	41.950	0.290	
5	240	41.890	0.230	
6	360	41.825	0.165	
7	480	41.775	0.115	
8	600	41.740	0.080	
9	900	41.690	0.030	
10	1200	41.665	0.005	
11	1800	41.650	-0.010	

Appendix C4
Cap and Liner Seepage Assessment

In this appendix PPK Environment & Infrastructure has assessed the potential for seepage of radionuclides from a repository trench. A modelling exercise also examined potential cap materials to minimise seepage.

C4.1. Introduction

PPK Environment & Infrastructure (PPK) assessed potential design options for the repository through:

- collection and laboratory analysis of soil samples for use as capping material
- hydrological model simulations using the US Environment Protection Agency (US EPA) approved Hydrological Evaluation of Landfill Performance (HELP) computer model
- inspection of drill core from the repository site and the conduct of point load index tests
- preliminary assessment of slope stability of the repository excavation.

C4.2. Assessment of Capping and Liner Material

C4.2.1 Laboratory Analysis

In order to assess the potential suitability of overburden soils and weathered siltstone for use as a low permeability compacted liner or barrier layer in the repository, cap samples were collected from a disused shale quarry southeast of Site 52a and from the drill core from the previous Department of Industry, Science and Resources (DISR) investigations.

The following laboratory testing was undertaken on samples recovered from the test pits and the slimes:

- 7 Atterberg limits (plastic limit, liquid limit, plasticity index, linear shrinkage)
- 3 standard compaction tests
- 8 particle size distribution tests
- 4 Emerson dispersion tests
- 6 permeability tests.

C4.2.2 Results

The shale quarry site comprises a gravelly silty sand topsoil layer overlying a gradational profile of residual soil to extremely weathered to distinctly weathered shale. Four samples were obtained from the soil and weathered shale exposed at the quarry site.

Inspection of the drill core from an earlier investigation by the DISR indicated variable near-surface conditions from soils that could be used for construction of a low permeability barrier or liner. The following general profile was noted:

- 40aE, gravelly sandy clay, brown, 0.15eb–0.7 m
- 40aW, silty sandy clay, brown, 0.0–2.6 m
- 45aSE, gravelly silty sand, brown, 0.2–1.0 m
- 52aNE, gravelly silty sand, 0.0–1.3 m and sandy gravelly clay, orange brown, 1.3-1.9 m
- 52aSW, gravelly sandy clay, red/orange brown, 0.5–1.6 m.

The laboratory test results are included in the attachments to this appendix and summarised in Table C4.1.

TABLE C4.1 Results of geotechnical testing

Sample/test	Emerson	Liquid limit	Plastic limit	Plasticity index	MDD/OMC	Permeability (K)	Description	MDD/OMC Ratio of K test
Sample 1, topsoil	8	–	NP	–	1.28 t/m^3 35.5%	1x10^{-6} m/s 8x10^{-7} m/s	sandy gravel	95%MDD, OMC 95%MDD, +3%OMC
Sample 2, residual soil	4	55	41	15	1.28 t/m^3 35.5%	7x10^{-7} m/s 1x10^{-7} m/s	sandy gravel some clay	95%MDD, OMC 95%MDD, +3%OMC
Sample 3, EW–HW shale	8	70	37	33	1.2 t/m^3 25%	4x10^{-7} m/s 2x10^{-7} m/s	sandy gravel some clay	95%MDD, 0MC 95%MDD, +3%OMC
Sample 4, MW shale	8	77	56	21	1.2 t/m^3 25%	–	sandy gravel some clay	–
40aW, 0.7–2.35 m	–	64	24	40	–	–	sandy clay	–
40aSW, 1.0–2.0 m	–	55	15	40	–	–	sandy clay	–
45aSE, 1.35–2.8 m	–	59	24	35	–	–	sandy clay	–
45aNW, 0.15–1.2 m	–	53	17	36	–	–	sandy clay	–

MDD = maximum dry density
OMC = optimum moisture content

The results indicate that the gravelly silty sand and weathered shale can be used to produce a homogeneous earthfill for placing as a cap over the repository. On the basis of the hydraulic conductivity tests this material would not be suitable for constructing a low permeability barrier layer in the cap or liner at the base of the repository. The higher permeability is probably associated with the low clay content (material <2 μm) of the materials tested.

There was insufficient drill core material of sandy clay residual soil to conduct hydraulic conductivity tests. However on the basis of the Atterberg limits and particle size distribution it is considered that this material should be suitable for construction of a compacted clay liner or barrier layer in the cap with a permeability expected to be less than 1x10^{-9} m/s. Additional sampling and analysis will be required to confirm the distribution and geotechnical properties of the sandy clay material.

C4.3. HELP Modelling

C4.3.1 Introduction

PPK completed a series of hydrological model simulations using the HELP Computer Model to assess the potential infiltration of rainwater through various capping and base lining systems (Shroeder 1994a, b).

The objective of the modelling was to estimate the leakage rates through the proposed national repository. The performance (or infiltration rate) is highly dependent on several factors, particularly elements of the capping system and the materials used to construct the capping systems.

The HELP model is a two dimensional hydrologic model for conducting site specific water balance of waste repositories and capping systems. The model accepts weather, soil and design data and uses solution techniques that account for the effects of surface storage, surface runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, unsaturated vertical drainage and leakage rates through various lining systems.

A number of different alternative capping and liner systems were assessed, including low permeability clay barrier layer in the cap, low permeability liner at the base of the repository, homogeneous earthfill cap and a composite barrier layer in the cap (incorporating a high density polyethylene (HDPE) geomembrane and low permeability compacted clay).

The results were further checked by a manual calculation of the percolation rate using the rainfall data for a short-term storm event. This storm event, expressed as a maximum storm intensity per hour (mm/hr), was used to calculate the vertical percolation rates.

C4.3.2 Model Assumptions

The various inputs required for the HELP model include site specific climatic data, concept designs and probable vegetative cover over the capping layer. The materials that make up the capping system can greatly affect the infiltration rates through the system. For this reason, PPK completed several model simulations using a combination of materials. Soil properties were determined from geotechnical testing of samples obtained from a shale quarry near Site 52a and from drill core from DISR investigations.

The HELP model assumptions included the following:

- Weather data from the Woomera Aerodrome was used and included temperature, precipitation and solar radiation information for Woomera.
- It was assumed that 75% of the capping layer could be classed as a watershed zone. The remainder (for example the crown of the slopes) is classed as a vertical percolation zone. For conservative reasons, a poor stand of grass was assumed to be present in the capping layer.
- Soil and material parameters were assumed from the geotechnical test results and default parameters from the HELP model. Where possible, laboratory permeability results were compared to the default soil parameters provided in the HELP software to assist in the selection of soil layer types.
- A slope of 10% was assumed for the final surface layer of the cap. For conservative reasons, in any scenarios where clay was modelled at the base, a zero slope gradient was modelled.
- For the drainage layer in the cap, default parameters for a sand layer were used in order to obtain appropriate porosity and wilting point values. Where a clay barrier was proposed (in the cap or base), a saturated vertical permeability of $1x10^{-9}$ m/s was assumed.
- These cases did not include any leachate recirculation within the repository cap.
- A sensitivity analysis was conducted for varying evaporative depths, which was the key parameter influencing the amount of infiltration. A number of evaporative zone depths were assessed by the model, however experience in similar climatic regions suggested that actual evaporative zone depths would be in the order of 1 m or greater.

C4.3.3 Model Parameters

A total of eight cases were modelled using the HELP computer package. Each simulation comprised a series of layers that made up a typical cross section of the landfill. Each simulation provided output data for the modelled cases. Table C4.2 below summarises the landfill cases modelled.

C4.3.4 Data Sources

All climate data was obtained from the Bureau of Meteorology, for Woomera, South Australia. As part of quality control, the default weather station data stored in the HELP model for Woomera was checked against the last 10 years of weather data obtained from the bureau. The data correlated well and it was accepted that the default data stored in the model was representative of the expected weather conditions. Default values for average wind speeds, quarterly relative humidity, annual precipitation and sunshine hours for Woomera were used.

TABLE C4.2 Summary of landfill cases assessed using the HELP computer model

Case reference	Description	Low permeability liner at base of trench	Drainage layer in cap
1a	Homogeneous soil cap comprising 2.5 m of loamy sand and 2.5 m of sandy loam capping overlying waste	No	No
1b	Homogeneous soil cap comprising 5 m of sandy loam overlying waste; a low permeability clay barrier 0.6 m thick placed at the base of the trench	Yes	No
2a	Capping layer comprising 1 m of soil, 0.6 m of low permeability clay, 3.4 m of soils overlying the waste	No	No
2b	Capping layer of 1 m of soil, overlying a composite liner comprising a HDPE geomembrane and 0.6 m clay barrier and 2.6 m of soils overlying the waste	No	Yes
2c	Capping layer comprising 1 m of soil overlying a 0.6 m thick clay barrier and lateral drainage sand layer and 3.2 m of soil overlying the waste; 0.6 m thick clay liner at the base of the repository	Yes	Yes
3a	Capping layer comprising 4.4 m of soils overlying a 0.6 m thick clay barrier	No	No
3b	As 3a above, but includes a 0.6 m clay barrier at the bottom of the trench	Yes	No
4	Capping layer of 1 m of soils overlying a HDPE geomembrane, 4 m of soil overlying the waste, with a 0.6 m clay liner placed at the base of the trench	Yes	Yes

A 10-year modelling period was selected. A review of the individual daily precipitation data stored in the default HELP model indicated a storm event of 60 mm over a 24-hour period would be included. Annual precipitation rates of approximately 180–250 mm were modelled over the 10-year period.

Solar radiation data were calculated based on the number of hours of sunlight and the cloud cover of Woomera.

C4.3.5 Model Outputs

An assessment of the results indicates that the model was sensitive to both slope angle and evaporative depth. An increase in the slope (from an initial 5% to 10%) generally reduced the vertical percolation for each case modelled. An increase in lateral runoff was also observed, particularly during periods of high daily rainfall.

The slope angle was set at 10% for all cases modelled, to represent the approximate restoration profile for the capping layers. This removed the effects of variable slope angles and enabled the model outputs to represent variations in vertical percolation due to the effects of evaporative zone depth (or root zone depth). The annual vertical percolation rates through the base of the trench for evaporative zone depths 0.3 m, 0.5 m and 1.0 m are presented in Tables C4.3–C4.5 respectively. In addition, cumulative percolation and volumes for the 10-year monitoring period is presented in Table C4.6.

The outputs indicated the following:

- The best performance (lowest vertical percolation through the base of the repository) was achieved with results from cases 2a, 2c and 5.
- The percolation rates were very sensitive to the evaporative zone depth. Generally each case performed worse with a shallow evaporative zone depth.

TABLE C4.3 Summary of annual percolation rates for 10-year modelled period, evaporative zone depth 0.3 m

Annual total percolation rates through base of repository (metres)										
Case reference	**Year**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1a	0	0	0	0.0013	0	0.0013	0.008	0.019	0.012	0.01
1b	0.00015	0.000125	0.00025	0.00031	0.00044	0.00048	0.0006	0.00064	0.00083	0.0023
2a	0.023	0.011	0.0013	0.013	0.001	0.0013	0.018	0.0012	0.009	0.035
2b	0.022	0.011	0.002	0.012	0.01	0.00055	0.019	0.0004	0.009	0.034
2c	0	0	0.0012	0	0.0012	0.0012	0.0012	0.0012	0.0012	0.0026
3a	0.022	0.005	0.009	0.011	0.01	0.0013	0.018	0.0013	0.009	0.026
3b	0.022	0.0117	0.0036	0.011	0.01	0.01	0.0006	0.0004	0.009	0.037
4	0.0004	0.00054	0.0007	0.0009	0.001	0.0011	0.00126	0.00135	0.0014	0.0019

TABLE C4.4 Summary of annual percolation rates for 10-year modelled period, evaporative zone depth 0.5 m

Annual total percolation rates through base of repository (metres)										
Case reference	**Year**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1a	0	0	9.10E-20	0.0013	0.0064	0.016	0.016	0.013	0.0153	0.0129
1b	1.30E-05	6.40E-06	1.10E-05	2.50E-07	2.20E-06	4.80E-06	3.20E-05	3.30E-06	2.70E-06	0.00013
2a	0	0	0	0	0	0	0	0	0	0
2b	1.30E-05	6.40E-06	1.10E-05	2.50E-07	2.20E-06	4.80E-06	3.20E-05	3.30E-06	2.70E-06	0.00013
2c	0	0	0	0	0	0	0	0	0	0
3a	0	0	0	0	0	0	0	0	0	0
3b	1.30E-05	6.40E-06	1.10E-05	2.50E-07	2.20E-06	4.80E-06	3.20E-05	3.30E-06	2.70E-06	0.00013
4	3.20E-07	7.00E-07	1.20E-06	1.20E-06	1.20E-06	1.30E-06	2.10E-06	2.40E-06	2.40E-06	5.30E-06

TABLE C4.5 Summary of annual percolation rates for 10-year modelled period, evaporative zone depth 1.0 m

Case reference	Annual total percolation rates through base of repository (metres)									
	Year									
	1	2	3	4	5	6	7	8	9	10
1a	0	0	0.01	0.0296	0.031	0.027	0.035	0.049	0.041	0.036
1b	0.00018	0	0.0003	0.00053	0.0015	0.0074	0.018	0.023	0.037	0.034
2a	0	0	0	0	0	0	0	0	0	0
2b	0.000113	0.000113	0.000113	0.000113	0.000113	0.000113	0.000113	0.000113	0.000113	0.000113
2c	0	0	0	0	0	0	0	0	0	0
3a	0	0	0	0	0	0	0	0	0	0
3b	0.00025	0.000396	0.00015	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0

TABLE C4.6 Cumulative percolation and volumes estimated through base of trench over 10 years

Case reference	Accumulated percolation and volume over 10 year period modelled					
	Evap zone depth 0.3 m		Evap zone depth 0.5 m		Evap zone depth 1.0 m	
	Percolation (m)	Volume (m^3)	Percolation (m)	Volume (m^3)	Percolation (m)	Volume (m^3)
1a	0.051	518	0.08	804	0.26	2586
1b	0.0061	61.3	0.093	91.4	0.12	1208
2a	0.12	1233	0	0	0	0
2b	0.121	1250	0.0002	2	0.00011	1.1
2c	0.009	91	0	0	0	0
3a	0.116	1156	0	0	0.001	13
3b	0.1254	1221	0.0002	2	0.0013	12.7
4	0.015	145	0	0.09	0.000184	1.85

- The soil cover capping layers (cases 1a and 1b) performed well when the evaporative zone depth was 0.3 m. However, vertical percolation rates and volumes migrating through the repository increased dramatically when the evaporative zone depth was increased to 0.5 m and deeper. Option 1b, which included a clay barrier at the base of the repository, indicated an improved performance in the percolation (and volumes) migrating through the repository.
- Annual total percolation rates varied depending on the precipitation rates. A review of the individual daily percolation rates indicated reduced performance following a storm. This was not the case for capping options that included a low permeability clay barrier or geomembrane, which were generally considered to be less responsive to percolation rates.
- Clay barriers constructed beneath a 1 m soil covering layer reduced the vertical percolation rates dramatically. Performance was enhanced further by the addition of a geomembrane in contact with the clay barrier layer.
- The effects of constructing a clay barrier at depth was also modelled (cases 3a and 3b). Performances were similar to case 2a (shallow clay barrier 1 m below cover soils). However, there was potential for increased infiltration due to water build up from steady percolation.
- A single geomembrane (case 5) performed marginally worse than the composite capping option of case 2a.
- A sensitivity check of case 2c was completed to assess the effects of removing the lateral sand drainage layer. The output results indicated the performance at evaporative zone depths of 0.5 m and greater were not affected. An increased vertical percolation rate was observed where the evaporative zone depth was 0.3 m.

C4.3.6 Model Verification

Due to the limitations of the HELP model in assessing the vertical percolation rates for storm intensities of less than 1 day, a manual calculation was completed to assess the vertical percolation rates for storm intensities of 1 hour duration. The impact of high intensity storm events is reduced by averaging daily precipitation totals over the chosen modelling period. An assessment of storm intensities was completed for weather station data obtained from the Bureau of Meteorology for Woomera. The following was noted:

- The greatest annual precipitation for the last 10 years was recorded in 1997.
- A storm intensity of 19 mm/hr was observed on 6 February 1997.
- Percolation was estimated assuming a runoff coefficient based on the soil type at the surface and assuming no sheet flow occurs.

Using storm data from Woomera, the following rates of percolation were calculated. This uses a coefficient of runoff based on slope and a general clay soil type.

- Percolation: 7.7–9.9 mm during storm events in 1997 and 2001.

The percolation rate is the total vertical percolation into the surface soil. This result is significant as the pattern of rainfall in the region is generally short storm events, rather than an even distribution throughout the year. However, the above calculation is conservative as it assumes that the soil layer prior to the storm event is 100% saturated. The percolation rates estimated are considered to exceed a typical 1 in 100 year storm event of an hour duration for Woomera (60 mm; Pilgrim 1997; Canterford 1987) when the proportion of vertical percolation in percentage terms is compared to the total rainfall, proportion of runoff during a typical storm event. It is expected that increased surface runoff would occur during storm events.

A manual monthly water balance was also calculated based on Thornthwaite and Mather (1957). This used monthly climate results, which were an average of 10 years for Andamooka. Percolation levels were estimated as zero for a typical 12 month period. This confirmed the need to assess vertical percolation rates manually.

C4.3.7 Discussion

The results of the model indicate the importance of the storm events and the evaporative zone depth in controlling vertical percolation through the repository. The following comments are provided:

1. Any variability in the hydraulic conductivity of a cover soil is significant.
2. A low permeability clay cap significantly reduces the impact of any cover soil variability. A 0.6 m thick low permeability layer is more effective than a 5 m thickness homogeneous earthfill cover at all evaporative zone depths.
3. The root zone depth (evaporative zone depth) will dictate the percentage of percolated water in the cover soil that is potentially affected by evaporative forces. The likelihood of greater evaporation is reduced with increased root depth. Wetted zones will generally develop at the root depth. Any surplus water at the root depth during storm events will be more readily available to migrate vertically downwards. This is reflected in the output results.
4. It is likely that the root zone depth for a poor stand of grass would be greater than 0.5 m.
5. The provision of drainage layers over surface capping layers only marginally improves the performance of the capping system. A review of the daily percolation rates indicated that the vertical percolation rates were reduced slightly during storm events. However, the performance of comparable capping systems with shallow barriers (typically 1 m below a cover soil) indicated that this effect was not significant for evaporative zone depths of 0.5 m or greater.
6. The evaporative zone depth is important in maintaining the moisture condition of a clay cap. Experience shows that the evaporative zone depth is likely to be 1 m in semi-arid conditions. Wetting and drying cycles of a clay barrier may cause an increase in the vertical permeability. This would substantially reduce the effectiveness of this layer to resist vertical migration of water. Additional investigations would be required to confirm whether there are sufficient sources of clay material able to produce a low permeability barrier layer (1×10^{-9} m/s).
7. Storm events would cause the greatest percolation rate immediately after construction, and before vegetation could be established. The HELP model cannot assess storm events of less than a 1 day duration. Further verification of storm events for time intervals less than 1 day were completed by hand.
8. The presence of a HDPE layer effectively reduced the percolation to zero for evaporative zone depths of 0.5 m or greater and above. The best performance was achieved with a composite clay/geomembrane barrier placed 1 m below a cover soil.

The assessment indicated the potential for prolonged vertical percolation through a homogeneous earthfill cap due to the possibility of high vertical percolation when root zones are deep.

Clay barrier layers in the cap at a shallow depth perform better but may be susceptible to cracking due to prolonged wet/dry cycles. Shallow clay barriers may also be susceptible to burrowing animals.

A clay barrier placed above the waste, although less susceptible to shrinkage, would be subjected to increased hydraulic heads due to the expectedly high vertical percolation rates predicted through the cover soils in extreme rainfall events, assuming that the soil is in a saturated condition.

It is considered that a composite lining system incorporating a geomembrane liner placed directly onto a compacted clay barrier layer provides the best level of protection from infiltration. This is particularly so during storm events. The incorporation of a geotextile over the geomembrane would reduce the potential for damage and provide some lateral drainage.

C4.4. Repository Development

This section provides a preliminary slope stability assessment for the proposed repository and assessment of excavation issues. The assessment is based on a review of bore logs provided by the Bureau of Rural Sciences, inspection of the core located in the Canberra Core Laboratory and the conduct of Point Load Index testing.

C4.4.1 Rock Mass Characteristics

The rock mass characteristics such as orientation of defects, strength of the rock will influence the stability of excavations and the construction of the repository.

Defects in the rock include bedding plane partings, clay seams and shear zones and joints. Bedding at the three sites is essentially flat lying, predominantly varying from 0–8 degrees, with in some cases cross bedding to 30 degrees. Bedding surfaces are planar and smooth with some bedding plane shears noted. Joints are well developed in the rock mass with the following orientations noted:

- Site 40a, 70–90 degrees dominantly 80 degrees, planar rough, 0.5–2 m spacing
- Site 45a, 75–90 degrees, dominantly 80 degrees, some to 30 degrees, planar rough, 0.5–2m spacing
- Site 52a, 60–75 degrees, some 45 degrees, planar rough, 0.6–1.0 m and 1–2 spacing.

The point load index test provides a strength index that can be correlated with the unconfined compressive strength of the rock.

Information on the defect spacing and unconfined compressive strength can be used to provide an indication of excavatability of materials within the repository.

Table C4.7 provides a summary of conditions at the sites based on the bore logs and testing.

TABLE C4.7 Interpreted site conditions

Repository site	Formation	General defect spacing (fractures/m)	Point load index (MPa)	Unconfined compressive strength(1) (MPa)	Interpreted excavation requirements
Site 40a	Simmons Quartzite	16/m, 5–8 m 8–12/m, 8–15 m	1.91–4.33@40ae 1.19–1.84@40aw 13.12@14.62m in 40aw	45.8–10.9 28.6–44.2 314.9	Bulldozer ripping and blasting to loosen
Site 45a	Simmons Quartzite	24/m, 5–7 m some higher 8–12/m, 5–11 m some 4–8/m, 8–12/m, 11–15 m	4.05–5.29@45ase 2.07–5.12@45anw	97.2–127 49.7–122.9	Bulldozer ripping and blasting to loosen
Site 52a	Bulldog Shale Cadna-owie Formation	12–24/m, 5–12 m 16–24/m, 3–7 m 8–12/m, 12–15 m	1.06–1.48@52ae 6.74@13.3m,52ae 0.58–0.8@52aw	21.2–29.6 161.8 11.6–16	Bulldozer ripping, may require blasting to loosen in Cadna-owie Formation and zones of low fracture spacing in lower section of excavation

(1) Unconfined compressive strength in shale based on 20xIs50 and 24xIs50 for sandstone and quartzite

The preliminary assessment indicates that the strength and defect spacing will influence the excavatability of the repository. In Site 52a, which is underlain by Bulldog Shale, it is likely that the repository excavation should be able to be excavated using a large bulldozer (D9–D10) with ripping required. In some areas ripping will be at the limit of equipment effectiveness. Where the Cadna-owie Formation is located in the lower sections of the excavations, and where the rock strength of the Bulldog Shale is expected to be higher and defect spacing is less, there is likely to be a need to undertake blasting to loosen the rock mass.

For Sites 40a and 45a, which are underlain by higher strength Simmons Quartzite, bulldozer ripping would be feasible in the upper sections of the excavation with blasting required in the lower portions of the excavation due to the higher rock mass strength.

C4.4.2 Slope Stability

The upper slopes would be influenced by the presence of highly erodible silty gravelly sand and the strength of the sandy clay residual soil and extremely weathered siltstone and sandstone.

A preliminary assessment indicates that the orientation of the joints would influence the stability of the repository walls. Establishing a slope angle parallel to the dominant dip of the joint would minimise the potential for significant slope failure. Excavation, filling and backfilling of the repository is expected to occur over a two month period.

On the basis of information from the bore logs, geotechnical testing, rock substance strength, orientation of joints and the short-term period of the excavation being open, the following preliminary slope design parameters are recommended:

- surface silty gravelly sand, 1:4 (vertical:horizontal)
- sandy clay residual soil and extremely weathered rock, 1:2 (vertical:horizontal)
- rock slope:
  - Site 40a, 80 degrees (parallel to the main joint set)
  - Site 45a, 80 degrees (parallel to the main joint set)
  - Site 52a, 60 degrees.

It is considered that there would be a need for temporary support for the excavated slopes in the form of meshing or rock bolts. Additional investigations are recommended to provide data on the orientation of the major defects to confirm the preliminary design slope angles. This should include the excavation of trenches or excavator pits or the drilling of additional orientated cored bores.

C4.5. Conclusion

The results indicate that the gravelly silty sand and weathered shale can be used to produce a homogeneous earthfill for placing as a cap over the repository. On the basis of the hydraulic conductivity tests this material would not be suitable for constructing a low permeability barrier layer in the cap or liner at the base of the repository. The higher permeability is probably associated with the low clay content (material <2 µm) of the materials tested.

There was insufficient drill core material of sandy clay residual soil to conduct hydraulic conductivity tests. However on the basis of the Atterberg limits and particle size distribution it is considered that this material should be suitable for construction of a compacted clay liner or barrier layer in the cap with a permeability expected to be less than $1x10^{-9}$ m/s. Additional sampling and analysis would be required to confirm the distribution and geotechnical properties of the sandy clay material.

The assessment indicates there is potential for prolonged vertical percolation through a homogeneous earthfill cap due to the possibility of high vertical percolation when root zones are deep.

Clay barrier layers located in the cap at a shallow depth perform better but may be susceptible to cracking due to prolonged wet/dry cycles. Shallow clay barriers may also be susceptible to burrowing animals.

A clay barrier placed at the base of the cover layer, although less susceptible to shrinkage, would be subjected to increased hydraulic heads due to the expectedly high vertical percolation rates predicted through the cover soils during extreme storm events and saturated conditions.

It is considered that a composite lining system incorporating a geomembrane liner placed directly onto a compacted clay barrier layer would provide the best level of protection from infiltration, particularly during expected storm events. The deployment of a HDPE liner would be relatively straightforward owing to the size of the repository and would provide a good marker horizon above the waste and deter burrowing animals. The incorporation of a geotextile over the geomembrane would reduce the potential for damage and provide some lateral drainage.

An assessment should be conducted on the need or otherwise to incorporate a coarse cobble layer (using excavated rock from the site).

On the basis of information from the bore logs, geotechnical testing, rock substance strength, orientation of joints and the short term period of the excavation being open, the following preliminary slope design parameters are recommended:

- surface silty gravelly sand, 1:4 (vertical:horizontal)
- sandy clay residual soil and extremely weathered rock, 1:2 (vertical:horizontal)
- rock slope:
  - Site 40a, 80 degrees (parallel to the main joint set)
  - Site 45a, 80 degrees (parallel to the main joint set)
  - Site 52a, 60 degrees.

It is considered that there would be a need for temporary support for the excavated slopes in the form of meshing or rock bolts. Additional investigations are recommended to provide data on the orientation of the major defects to confirm the preliminary design slope angles. This should include the excavation of trenches or excavator pits or the drilling of additional orientated cored bores.

The preliminary assessment indicates that the strength and defect spacing would influence the excavatability of the repository. In Site 52a, which is underlain by Bulldog Shale, it is likely that the repository excavation should be able to be excavated using a large bulldozer (D9–D10) with ripping required. In some areas ripping would be at the limit of equipment effectiveness. Where the Cadna-owie Formation is located in the lower sections of the excavations, and where the rock strength of the Bulldog Shale is expected to be higher and defect spacing is less, there is likely to be a need to undertake blasting to loosen the rock mass.

For Sites 40a and 45a, which are underlain by higher strength Simmons Quartzite, bulldozer ripping would be feasible in the upper sections of the excavation with blasting required in the lower portions of the excavation due to the higher rock mass strength.

C4.6. References

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C4.7. Attachment: Laboratory Test Results

SSL
Scientific Services Laboratory

TEST REPORT

COEFFICIENT OF PERMEABILITY

TEST METHOD AS1289. 6. 7.3

Client:	PPK Environment & Infrastructure Pty. Ltd.		
Project:	Unknown		
Client Ref. No:	102186A	Test date:	11 December, 2001

Sample details

Sampled by	Client
Preparation	Specimens compacted in five equal layers to 95% of Maximum Dry Density at OMC and at 3% wet of OMC Compaction data by client.

Test conditions

Saturated (cell pressure 600 kPa) to a mean effective stress of 100 kPa and percolated at 20 kPa hydraulic head. Permeant - Distilled water.

Test Results:

SSL Sample No. - Description		XT0836/1 - Dark red brown silty sand	
Client Sample No./Moisture Condition		1 / OMC	1/OMC + 3%
Specimen height/diameter	(mm)	104/102	104/102
Target Dry Density	(t/m^3)	1.17	1.17
Target Moisture Content	(%)	39.5	42.5
Moulding Moisture Content	(%)	39.5	42.1
Moulding Dry Density	(t/m^3)	1.17	1.17
Final Moisture Content	(%)	43.5	42.6
Density/Moisture Ratio	(%)	95.0/100.0	95.0/106.5
Coefficient of Permeability	(m/sec)	1×10^{-6}	8×10^{-7}

Remarks: Water oozed out of the mould during compaction of specimen at OMC+3%.

SSL Report Number: XT0836/R1

National Association of Testing Authorities, Australia
NATA Endorsed Test Report
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Signatory: C. Rovira
C Rovira

Date: 21 December, 2001 Sheet 1 of 3

NATA Accreditation Number: 165

AS/NZS ISO 9001 Quality System Certified Organisation
177 Salmon St, Port Melbourne, Vic, 3207 Telephone (03) 9248 4900 Fax (03) 9646 5165
A Business Unit of the Australian Government Analytical Laboratories (AGAL)
Industry, Science and Resources

SSL
Scientific Services Laboratory

TEST REPORT

COEFFICIENT OF PERMEABILITY

TEST METHOD AS1289. 6. 7.3

Client:	PPK Environment & Infrastructure Pty. Ltd.		
Project:	Unknown		
Client Ref. No:	102186A	Test date:	11 December, 2001

Sample details

Sampled by	Client
Preparation	Specimens compacted in five equal layers to 95% of Maximum Dry Density at OMC and at 3% wet of OMC Compaction data by client.

Test conditions

Saturated (cell pressure 600 kPa) to a mean effective stress of 100 kPa and percolated at 20 kPa hydraulic head. Permeant - Distilled water.

Test Results:

SSL Sample No. - Description		XT0836/2 - Light red brown mixture of silt, gravel & clay	
Client Sample No./Moisture Condition		2 / OMC	2/OMC + 3%
Specimen height/diameter	(mm)	104/102	104/102
Target Dry Density	(t/m^3)	1.22	1.22
Target Moisture Content	(%)	35.5	38.5
Moulding Moisture Content	(%)	35.5	38.6
Moulding Dry Density	(t/m^3)	1.22	1.22
Final Moisture Content	(%)	41.5	40.1
Density/Moisture Ratio	(%)	95.0/100.0	95.0/108.5
Coefficient of Permeability	(m/sec)	7×10^{-7}	1×10^{-7}

Remarks:

SSL Report Number: XT0836/R1

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Industry, Science and Resources

Scientific Services Laboratory

TEST REPORT

COEFFICIENT OF PERMEABILITY

TEST METHOD AS1289. 6. 7.3

Client:	PPK Environment & Infrastructure Pty. Ltd.		
Project:	Unknown		
Client Ref. No:	102186A	Test date:	11 December, 2001

Sample details

Sampled by	Client
Preparation	Specimens compacted in five equal layers to 95% of Maximum Dry Density at OMC and at 3% wet of OMC Compaction data by client.

Test conditions

Saturated (cell pressure 600 kPa) to a mean effective stress of 100 kPa and percolated at 20 kPa hydraulic head. Permeant - Distilled water.

Test Results:

SSL Sample No. - Description		XT0836/3 - Yellowish brown mixture of silt, gravel & clay	
Client Sample No./Moisture Condition		3 / OMC	3 /OMC + 3%
Specimen height/diameter	(mm)	104/102	104/102
Target Dry Density	(t/m^3)	1.14	1.14
Target Moisture Content	(%)	25.0	28.0
Moulding Moisture Content	(%)	25.1	28.1
Moulding Dry Density	(t/m^3)	1.14	1.14
Final Moisture Content	(%)	44.6	40.1
Density/Moisture Ratio	(%)	95.0/100.5	95.0/112.5
Coefficient of Permeability	(m/sec)	4×10^{-7}	2×10^{-7}

Remarks:

SSL Report Number: XT0836/R1

National Association of Testing Authorities, Australia
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C Rovira

Date: 21 December, 2001 Sheet 3 of 3 NATA Accreditation Number: 165

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Coffey Geosciences Pty Ltd A.C.N. 056 335 516

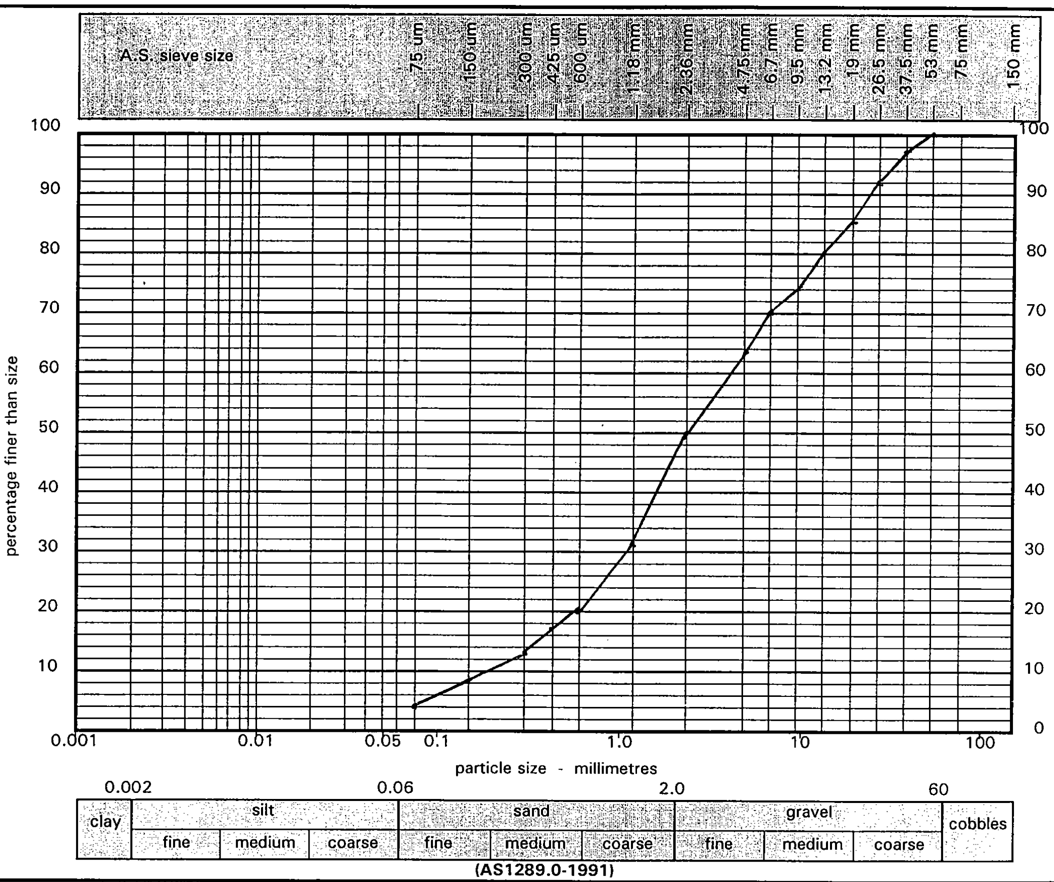
Geotechnical | **Resources** | Environmental | **Technical** | Project Management

14B Henley Beach Road, Mile End, SA, 5031
Ph: (08) 8352 1744, Fax: (08) 8234 0932

particle size distribution

client :	*PPK ENVIRONMENT & INFRASTRUCTURE PTY LTD*	job no :	*AL4104/1*
principal :		laboratory :	*ADELAIDE*
project :	*JOB NO. 27P112A*	report date :	*February 13, 2002*
location :		test report :	*26519*

test procedure :	*AS1289 3.1.1, 3.2.1, 3.3.1, 3.4.1 & 3.6.1*	depth :	
sample no :	*10124*		
sample identification:	*#1*		



Atterberg Limit :

liquid limit	%	-	**Sample History**	natural state ☐	**Preparation Method**	
plastic limit	%	-		air dried ☒	dry sieving ☒	
plasticity index	%	*NP*		oven dried ☐	wet sieving ☐	
linear shrinkage	%	*0*		other ☐	**Linear Shrinkage**	
natural moisture	%				Mould size *254* mm	
					crumbing ☐	
					curling ☐	

classification :

SANDY GRAVEL, FINE TO COARSE, RED-BROWN, SAND FINE TO COARSE

MAXIMUM DRY DENSITY 1.28 t/m3
OPTIMUM MOISTURE CONTENT 35.5%
AS1289 5.1.1

SAMPLE TESTED AS RECEIVED

NATA

This laboratory is accredited by the National Association of Testing Authorities, Australia. The test(s) reported herein have been performed in accordance with its terms of accreditation. This document shall not be reproduced except in full without the prior approval of the laboratory.

Authorised Signature
NATA No 1158

Coffey Geosciences Pty Ltd A.C.N. 056 335 516

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Coffey

determination of emerson class number

client :	*PPK ENVIRONMENT & INFRASTRUCTURE PTY LTD*	job no :	*AL4104/1*
principal :		laboratory :	*ADELAIDE*
project :	*JOB NO. 27P112A*	date :	*February 13, 2002*
location :		test report :	*26520*

test procedure : *AS1289 3.8.1* date sampled: *11/12/01* material source:
sample identification: *#1*

test data

air dried crumbs

time start of test: *8.51.13*

time dispersion commences:

time dispersion completed:

remoulded material

time start of test:

time dispersion commences:

time dispersion completed:

material description

SANDY GRAVEL, FINE TO COARSE, RED-BROWN, SAND FINE TO COARSE.

type of water used: *distilled*

water temperature: ° *C*

immersion of air dried crumbs

- does not slake ☒
- slakes ☐

(does not slake →)
- swell ☐ ⑦
- does not swell ☒ ⑧

(slakes →)
- complete dispersion ☐ ①
- partial dispersion ☐ ②
- no dispersion ☐

immersion of remoulded material

- disperses ☐ ③
- does not disperse ☐

calcite or gypsum
- present ☐ ④
- absent ☐

vigorous shaking
- disperses ☐ ⑤
- flocculates ☐ ⑥

Emerson class number *8*

Form Number L4.8R1 Version 5.0

NATA

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Authorised Signature
NATA No 1158

Coffey Geosciences Pty Ltd A.C.N. 056 335 516

Geotechnical | Resources | Environmental | Technical | Project Management

14B Henley Beach Road, Mile End, SA, 5031
Ph: (08) 8352 1744, Fax: (08) 8234 0932

particle size distribution

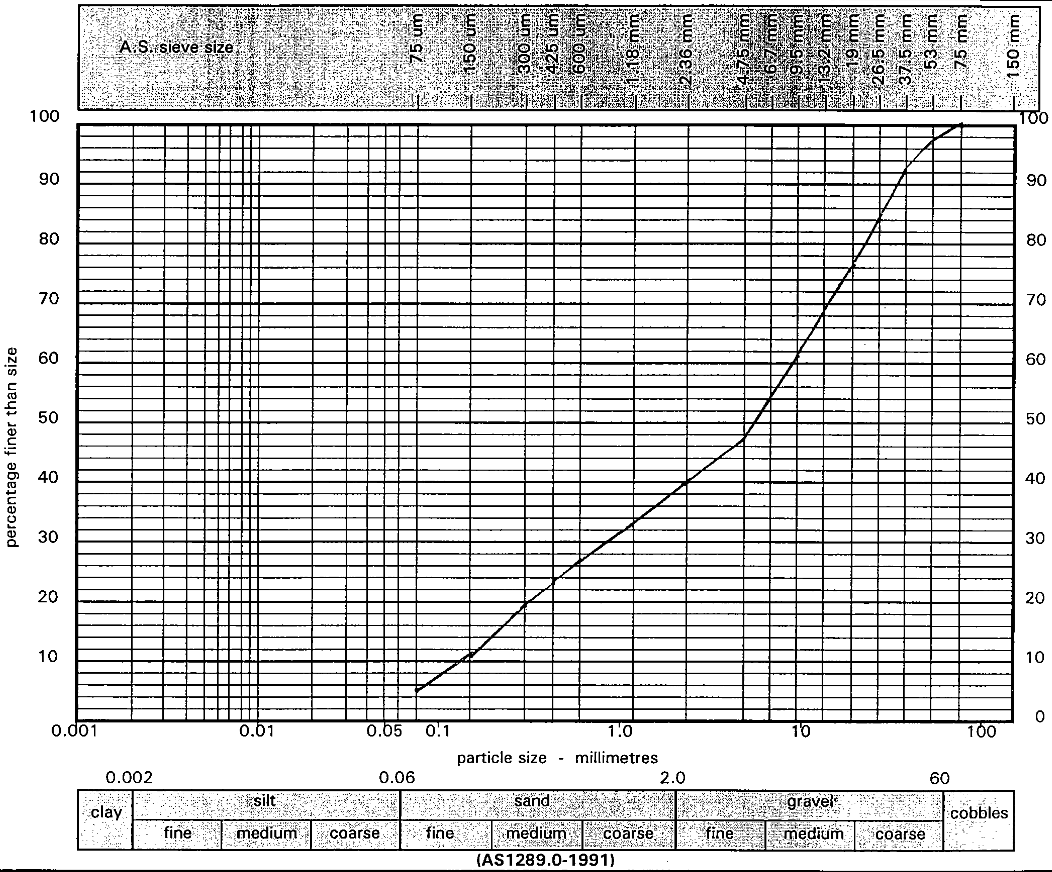
client :	*PPK ENVIRONMENT & INFRASTRUCTURE PTY LTD*	job no :	*AL4104/1*
principal :		laboratory :	*ADELAIDE*
project :	*JOB NO. 27P112A*	report date :	*February 13, 2002*
location :		test report :	*26521*

test procedure : *AS1289 3.1.1, 3.2.1, 3.3.1, 3.4.1 & 3.6.1* — depth :

sample no : *10125*

sample identification: *#2*

Form Number L1.8R1 Version 5.0



Atterberg Limit :

liquid limit	%	*55*
plastic limit	%	*41*
plasticity index	%	*15*
linear shrinkage	%	*6.5*
natural moisture	%	

Sample History

- natural state ☐
- air dried ☒
- oven dried ☐
- other ☐

Preparation Method

- dry sieving ☒
- wet sieving ☐

Linear Shrinkage

Mould size *254* mm

- crumbing ☐
- curling ☐

classification :

SANDY GRAVEL, FINE TO COARSE, RED-BROWN, SAND FINE TO COARSE WITH SOME HIGH PLASTICITY FINES

MAXIMUM DRY DENSITY 1.28 t/m3
OPTIMUM MOISTURE CONTENT 35.5%
AS1289 5.1.1

SAMPLE TESTED AS RECEIVED

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Ph: (08) 8352 1744, Fax: (08) 8234 0932

Coffey

determination of emerson class number

client :	*PPK ENVIRONMENT & INFRASTRUCTURE PTY LTD*	job no :	*AL4104/1*
principal :		laboratory :	*ADELAIDE*
project :	*JOB NO. 27P112A*	date :	*February 13, 2002*
location :		test report :	*26522*

test procedure : *AS1289 3.8.1* date sampled: *11/12/01* material source:
sample identification: *#2*

test data

air dried crumbs

time start of test: *8.51.38*

time dispersion commences:

time dispersion completed:

remoulded material

time start of test: *9.16.30*

time dispersion commences:

time dispersion completed:

material description

SANDY GRAVEL, FINE TO COARSE, RED-BROWN, SAND FINE TO COARSE WITH SOME HIGH PLASTICITY FINES.

type of water used: *distilled*

water temperature: ° *C*

immersion of air dried crumbs

- does not slake ☐ → swell ☐ ⑦ / does not swell ☐ ⑧
- slakes ☒
  - complete dispersion ☐ ①
  - partial dispersion ☐ ②
  - no dispersion ☒

immersion of remoulded material

- disperses ☐ ③
- does not disperse ☒
  - calcite or gypsum
    - present ☒ ④
    - absent ☐
      - vigorous shaking
        - disperses ☐ ⑤
        - flocculates ☐ ⑥

Emerson class number *4*

Form Number L4.8R1 Version 5.0

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Geotechnical | Resources | Environmental | Technical | Project Management

14B Henley Beach Road, Mile End, SA, 5031
Ph: (08) 8352 1744, Fax: (08) 8234 0932

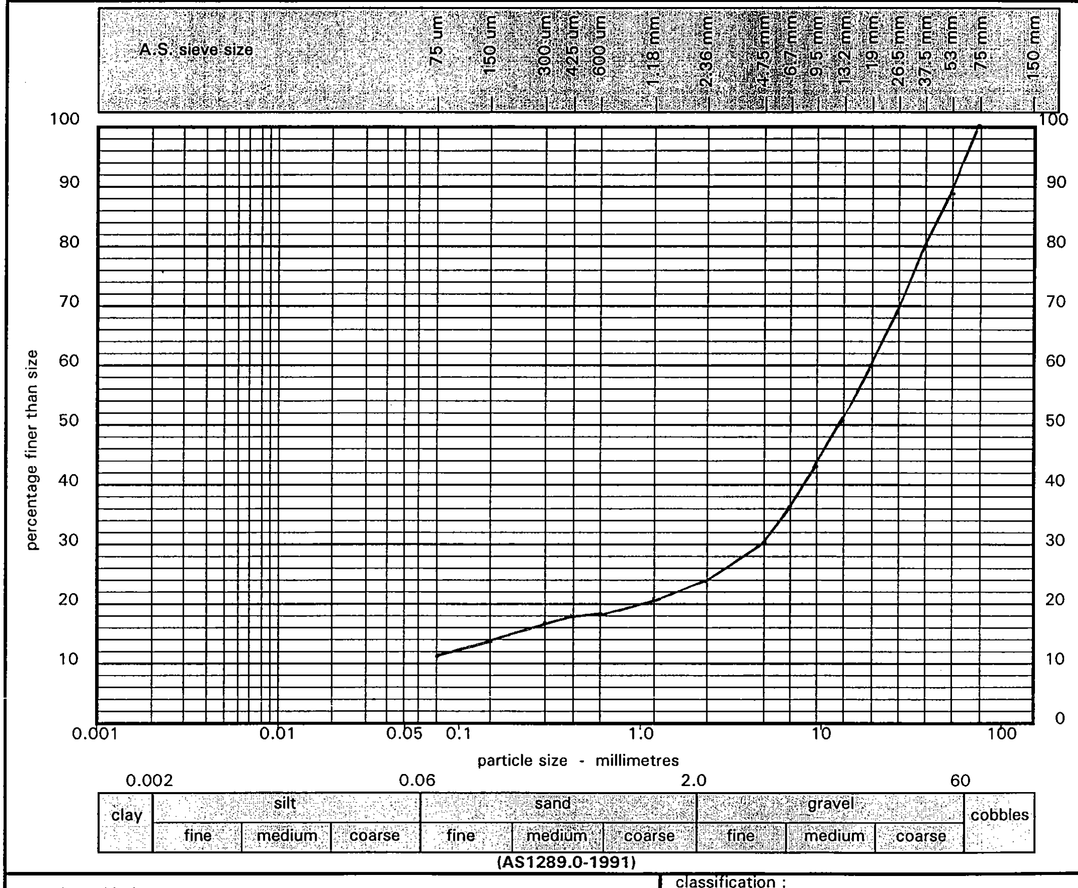
particle size distribution

client :	*PPK ENVIRONMENT & INFRASTRUCTURE PTY LTD*	job no :	*AL4104/1*
principal :		laboratory :	*ADELAIDE*
project :	*JOB NO. 27P112A*	report date :	*February 13, 2002*
location :		test report :	*26523*

test procedure : *AS1289 3.1.1, 3.2.1, 3.3.1, 3.4.1 & 3.6.1* depth :

sample no : *10126*

sample identification: *#3*



Atterberg Limit :

liquid limit	%	*70*
plastic limit	%	*37*
plasticity index	%	*33*
linear shrinkage	%	*11.5*
natural moisture	%	

Sample History

- natural state ☐
- air dried ☒
- oven dried ☐
- other ☐

Preparation Method

- dry sieving ☒
- wet sieving ☐

Linear Shrinkage

Mould size *254* mm

- crumbing ☐
- curling ☐

classification :

SANDY GRAVEL, FINE TO COARSE, ORANGE-BROWN, SAND FINE TO COARSE WITH SOME HIGH PLASTICITY CLAY FINES

MAXIMUM DRY DENSITY 1.20 t/m3
OPTIMUM MOISTURE CONTENT 25%
AS1289 5.1.1

SAMPLE TESTED AS RECEIVED

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148 Henley Beach Road, Mile End, SA, 5031
Ph: (08) 8352 1744, Fax: (08) 8234 0932

Coffey

determination of emerson class number

client :	*PPK ENVIRONMENT & INFRASTRUCTURE PTY LTD*	job no :	*AL4104/1*
principal :		laboratory :	*ADELAIDE*
project :	*JOB NO. 27P112A*	date :	*February 13, 2002*
location :		test report :	*26524*

test procedure : *AS1289 3.8.1* date sampled: *11/12/01* material source:
sample identification: *#3*

test data

air dried crumbs

time start of test: *8.54.50*

time dispersion commences:

time dispersion completed:

remoulded material

time start of test:

time dispersion commences:

time dispersion completed:

material description

SANDY GRAVEL, FINE TO COARSE, ORANGE-BROWN, SAND FINE TO COARSE WITH SOME HIGH PLASTICITY CLAY FINES.

type of water used: *distilled*

water temperature: ° *C*

immersion of air dried crumbs

- does not slake ☒
  - swell ☐ ⑦
  - does not swell ☒ ⑧
- slakes ☐
  - complete dispersion ☐ ①
  - partial dispersion ☐ ②
  - no dispersion ☐

immersion of remoulded material

- disperses ☐ ③
- does not disperse ☐
  - calcite or gypsum
    - present ☐ ④
    - absent ☐
      - vigorous shaking
        - disperses ☐ ⑤
        - flocculates ☐ ⑥

Emerson class number	*8*

Form Number L4.8B1 Version 5.0

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Geotechnical | **Resources** | Environmental | **Technical** | Project Management

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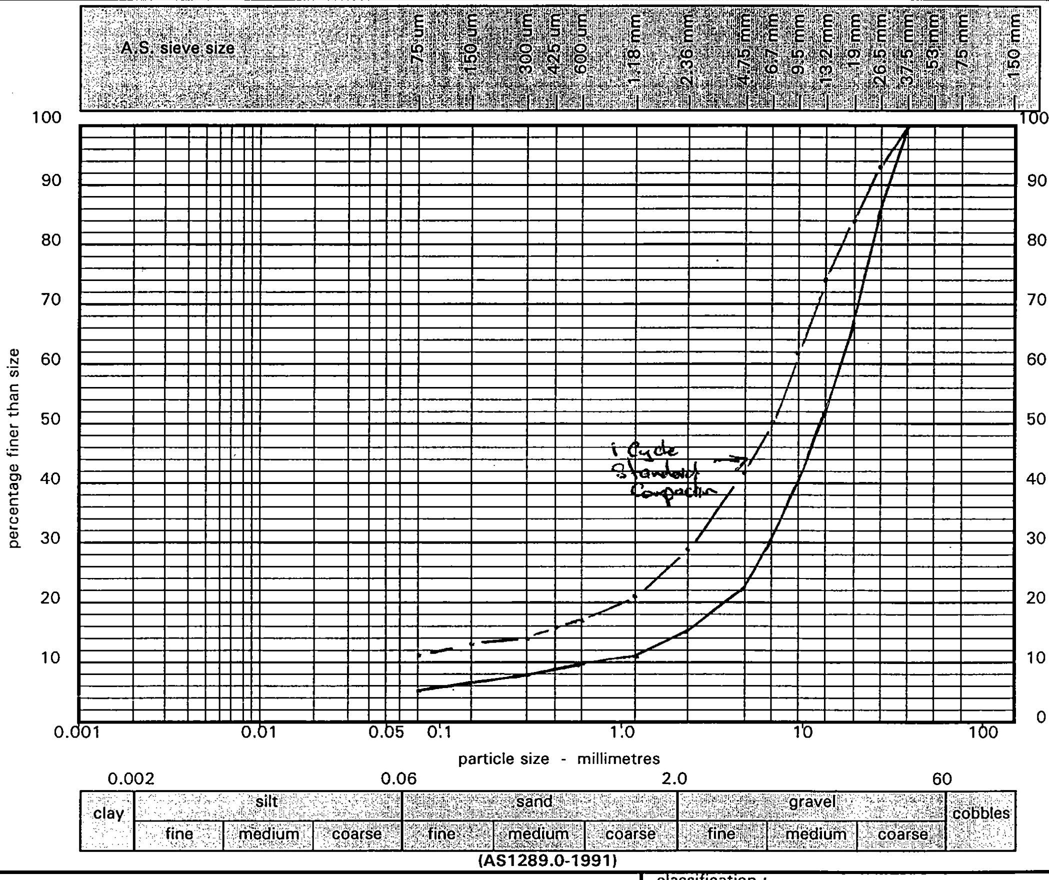
Ph: (08) 8352 1744, Fax: (08) 8234 0932

particle size distribution

client :	*PPK ENVIRONMENT & INFRASTRUCTURE PTY LTD*	job no :	*AL4104/1*
principal :		laboratory :	*ADELAIDE*
project :	*JOB NO. 27P112A*	report date :	*February 13, 2002*
location :		test report :	*26525*

test procedure : *AS1289 3.1.1, 3.2.1, 3.3.1, 3.4.1 & 3.6.1* depth :
sample no : *10127*
sample identification: *#4*



Form Number L1.8R1 Version 5.0

Atterberg Limit :

liquid limit	%	*77*
plastic limit	%	*56*
plasticity index	%	*21*
linear shrinkage	%	*7.5*
natural moisture	%	

Sample History

natural state	☐
air dried	☒
oven dried	☐
other	☐

Preparation Method

dry sieving	☒
wet sieving	☐

Linear Shrinkage

Mould size *254* mm

crumbing	☐
curling	☐

classification :
SANDY GRAVEL, FINE TO COARSE, SAND FINE TO COARSE, TRACE OF COBBLES, LIGHT BROWN, WITH A TRACE OF HIGH PLASTICITY CLAY FINES.

MAXIMUM DRY DENSITY 1.20 t/m3
OPTIMUM MOISTURE CONTENT 25%
AS1289 5.1.1

SAMPLE TESTED AS RECEIVED

Authorised Signature
NATA No 1158

Coffey Geosciences Pty Ltd A.C.N. 056 335 516

Geotechnical | **Resources** | Environmental | **Technical** | Project Management

14B Henley Beach Road, Mile End, SA, 5031
Ph: (08) 8352 1744, Fax: (08) 8234 0932

determination of emerson class number

client :	*PPK ENVIRONMENT & INFRASTRUCTURE PTY LTD*	job no :	*AL4104/1*
principal :		laboratory :	*ADELAIDE*
project :	*JOB NO. 27P112A*	date :	*February 13, 2002*
location :		test report :	*26526*

test procedure : *AS1289 3.8.1* date sampled: *11/12/01* material source:
sample identification: *#4*

test data

air dried crumbs

time start of test: *8.55.12*

time dispersion commences:

time dispersion completed:

remoulded material

time start of test:

time dispersion commences:

time dispersion completed:

material description

SANDY GRAVEL, FINE TO COARSE, SAND FINE TO COARSE, TRACE OF COBBLES, LIGHT BROWN, WITH A TRACE OF HIGH PLASTICITY CLAY FINES.

type of water used: *distilled*

water temperature: ° *C*

immersion of air dried crumbs

- does not slake ☒ → swell ☐ ⑦ / does not swell ☒ ⑧
- slakes ☐ →
  - complete dispersion ☐ ①
  - partial dispersion ☐ ②
  - no dispersion ☐ →

immersion of remoulded material

- disperses ☐ ③
- does not disperse ☐ → calcite or gypsum
  - present ☐ ④
  - absent ☐ → vigorous shaking
    - disperses ☐ ⑤
    - flocculates ☐ ⑥

Emerson class number *8*

Form Number 14.8B1 Version 5.0

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NATA No 1158

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Geotechnical | **Resources** | Environmental | **Technical** | Project Management

16 Mildura Street, Fyshwick, ACT 2609
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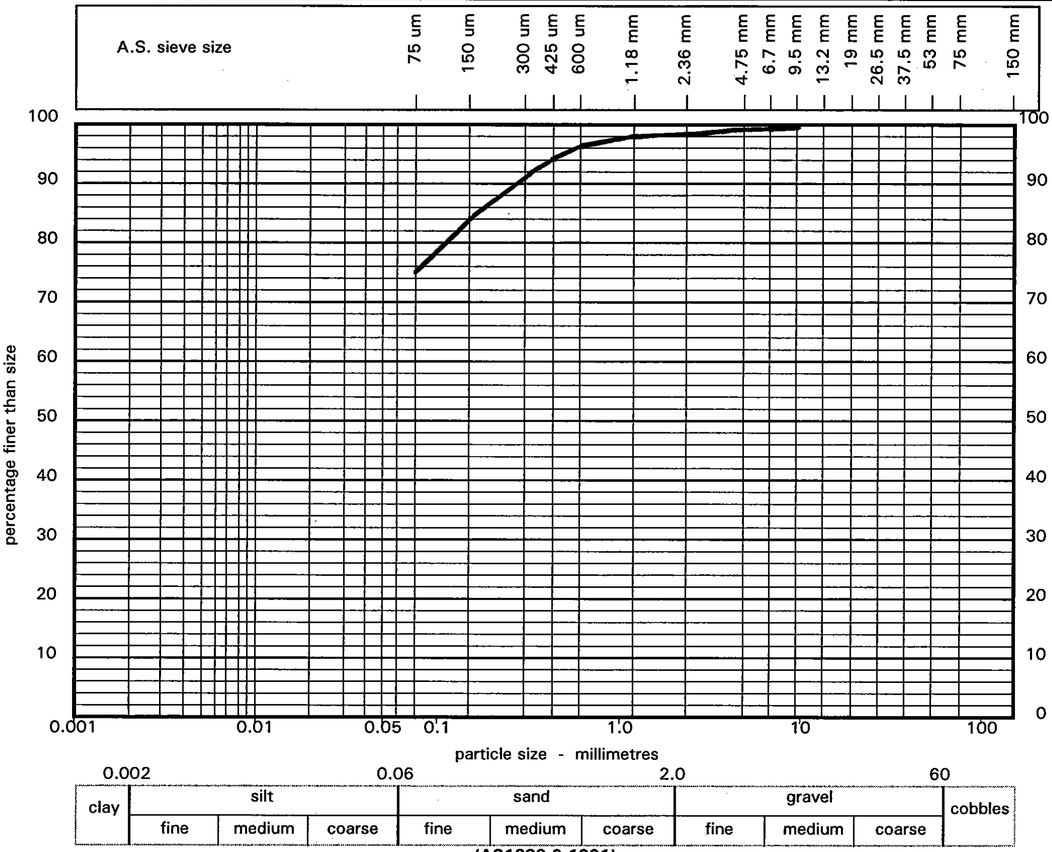
particle size distribution & atterberg limits

client :	*PPK ENVIRONMENT & INFRASTRUCTURE*	job no :	*DCL3060*
principal : -		laboratory :	*0*
project :	*GEOTECHNICAL TESTING*	report date :	*January 17, 2002*
location :	*CANBERRA, ACT*	test report :	*2002/86088*

test procedure : *AS1289 3.1.1, 3.2.1, 3.3.1, 3.4.1, 3.6.1.* depth : *0.7-2.35*
sample no : *86088*
sample identification: *RAD (ISR) 40 AW*

Form Number L1.8R1 Version 5.0



Atterberg Limit :

liquid limit	%	*64*
plastic limit	%	*24*
plasticity index	%	*40*
linear shrinkage	%	*15*
natural moisture	%	☒

Sample History

- natural state ☐
- air dried ☐
- oven dried ☒
- other ☐

Preparation Method

- dry sieving ☒
- wet sieving ☐

Linear Shrinkage

Mould size *254* mm

- crumbing ☐
- curling ☒

classification :
Sandy CLAY, high plasticity, orange brown, sand fine to coarse, trace fine gravel.

Sample received from client 18.12.2001.

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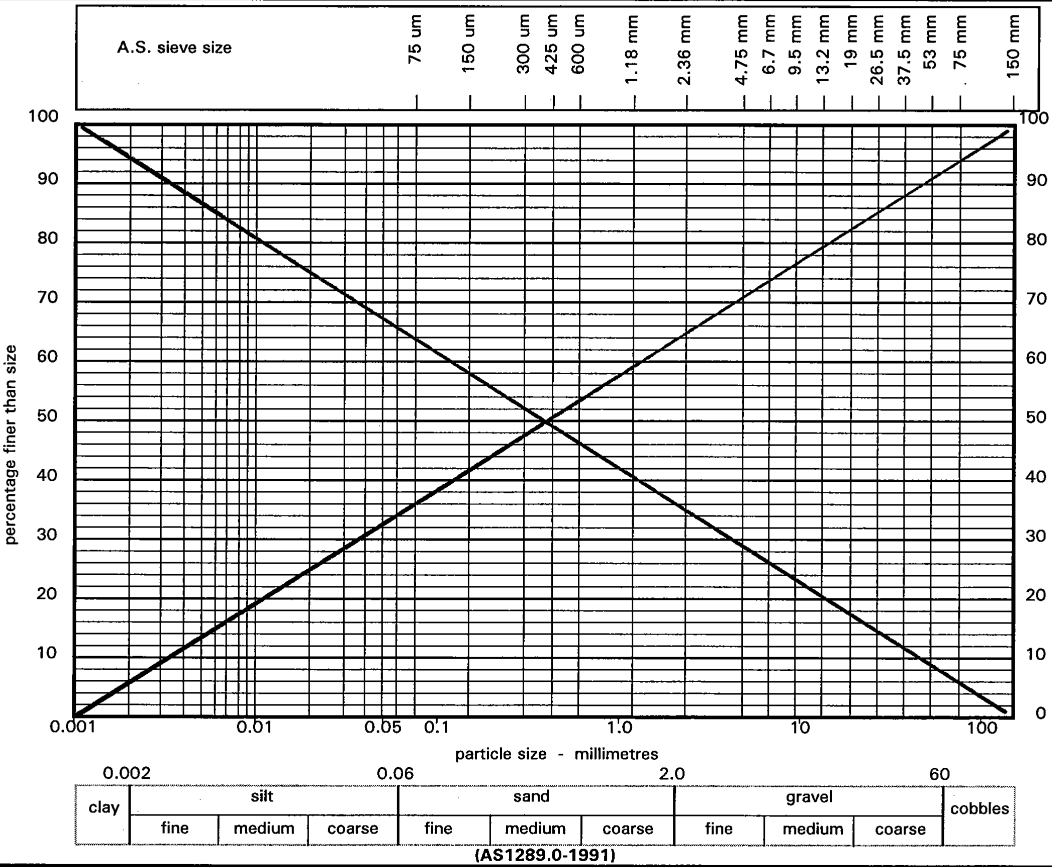
Geotechnical | **Resources** | Environmental | **Technical** | Project Management

16 Mildura Street, Fyshwick, ACT 2609
0

~~particle size distribution &~~ atterberg limits

client :	*PPK ENVIRONMENT & INFRASTRUCTURE*	job no :	*DCL3060*
principal : -		laboratory :	*0*
project :	*GEOTECHNICAL TESTING*	report date :	*January 17, 2002*
location :	*CANBERRA, ACT*	test report :	*2002/86089*

test procedure : *AS1289 3.1.1, 3.2.1, 3.3.1, 3.4.1.*   depth : *1.0-2.0*
sample no : *86089*
sample identification: *RAD (ISR) 40 ASW*



Atterberg Limit :

liquid limit	%	*55*	
plastic limit	%	*15*	
plasticity index	%	*40*	
linear shrinkage	%	*15½*	
natural moisture	%	☒ (crossed out)	

Sample History
- natural state ☐
- air dried ☐
- oven dried ☒
- other ☐

Preparation Method
- dry sieving ☒
- wet sieving ☐

Linear Shrinkage
Mould size *254* mm
- crumbing ☐
- curling ☒

classification :

Sample received from client 18.12.2001.

Authorised Signature [signature]
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Geotechnical | **Resources** | Environmental | **Technical** | Project Management

16 Mildura Street, Fyshwick, ACT 2609
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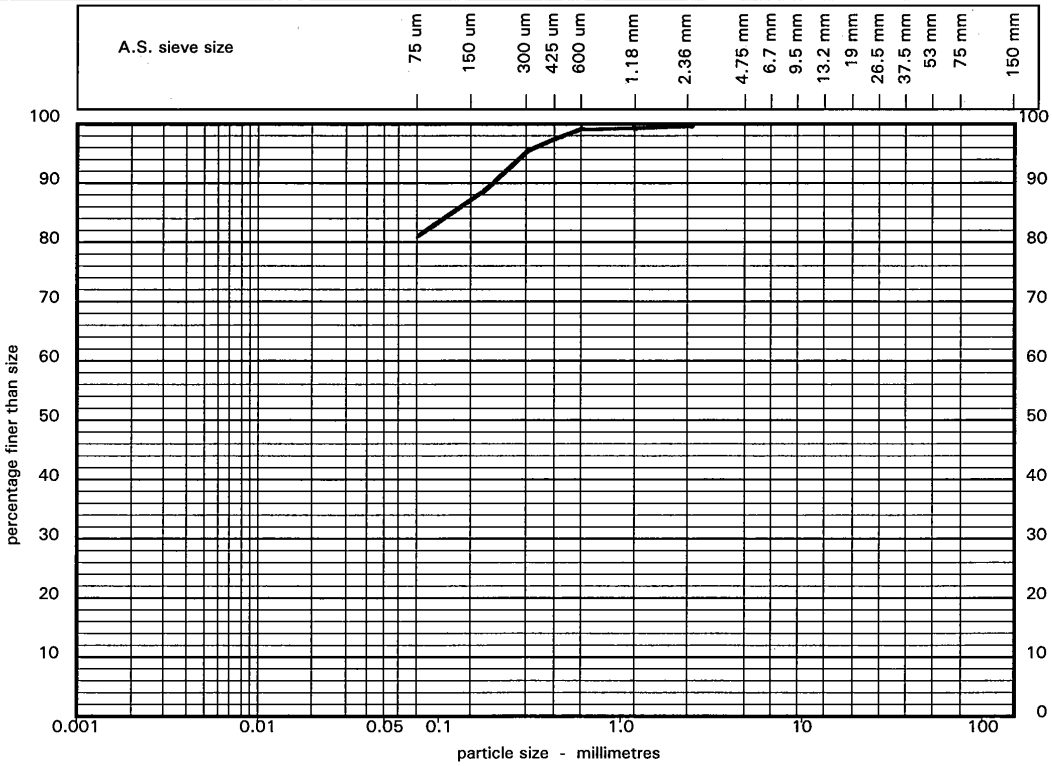
particle size distribution & atterberg limits

client :	*PPK ENVIRONMENT & INFRASTRUCTURE*	job no :	*DCL3060*
principal : -		laboratory :	*0*
project :	*GEOTECHNICAL TESTING*	report date :	*January 17, 2002*
location :	*CANBERRA, ACT*	test report :	*2002/86086*

test procedure :	*AS1289 3.1.1, 3.2.1, 3.3.1, 3.4.1, 3.6.1.*	depth :	*1.35-2.8*
sample no :	*86086*		
sample identification:	*RAD (ISR) 45 ASE*		



0.002				0.06			2.0			60
clay	silt			sand			gravel			cobbles
	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	

(AS1289.0-1991)

Atterberg Limit :

			Sample History		Preparation Method	
liquid limit	%	*59*	natural state	☐	dry sieving	☒
plastic limit	%	*24*	air dried	☐	wet sieving	☐
plasticity index	%	*35*	oven dried	☒	**Linear Shrinkage**	
linear shrinkage	%	*17½*	other	☐	Mould size *254* mm	
natural moisture	%	X			crumbing	☐
					curling	☒

classification :
Sandy CLAY, high plasticity, orange grey, brown, sand fine to coarse.

Sample received from client 18.12.2001.

Authorised Signature
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Geotechnical | **Resources** | Environmental | **Technical** | Project Management

16 Mildura Street, Fyshwick, ACT 2609
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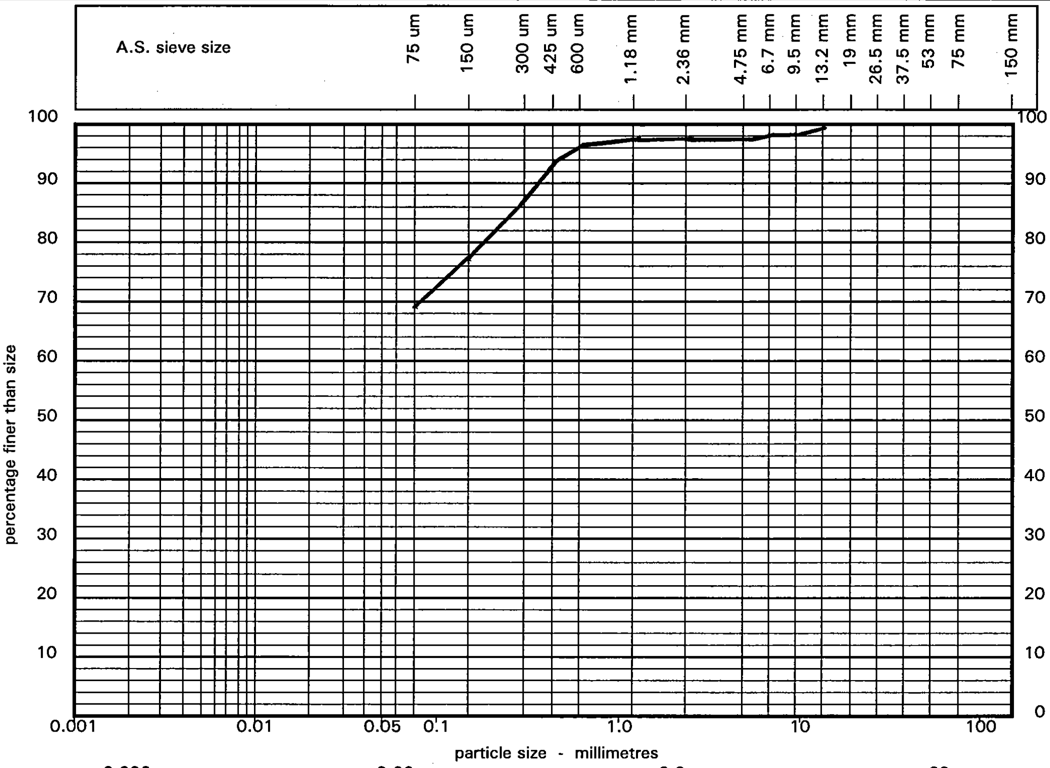
particle size distribution & atterberg limits

client :	*PPK ENVIRONMENT & INFRASTRUCTURE*	job no :	*DCL3060*
principal : -		laboratory :	*0*
project :	*GEOTECHNICAL TESTING*	report date :	*January 17, 2002*
location :	*CANBERRA, ACT*	test report :	*2002/86087*

test procedure :	*AS1289 3.1.1, 3.2.1, 3.3.1, 3.4.1, 3.6.1.*	depth :	*0.15-1.2*
sample no :	*86087*		
sample identification:	*RAD (ISR) 45 ANW*		

Form Number L1.8R1 Version 5.0



0.002			0.06			2.0			60	
clay	silt			sand			gravel			cobbles
	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	

(AS1289.0-1991)

Atterberg Limit :

liquid limit	%	*53*
plastic limit	%	*17*
plasticity index	%	*36*
linear shrinkage	%	*17½*
natural moisture	%	

Sample History

natural state	☐
air dried	☐
oven dried	☒
other	☐

Preparation Method

dry sieving	☒
wet sieving	☐

Linear Shrinkage

Mould size *254* mm

crumbing	☐
curling	☒

classification :

Sandy CLAY, high plasticity, dark orange brown, sand fine to coarse, trace fine gravel.

Sample received from client 18.12.2001.

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Coffey

Point Load Strength Index Test Results

Job No	DCL3060
Sheet	1 of 2
Client	PPK - Environemt & Infrastructure
Office	Canberra
Principal	
Date	20/12/01
Project	Point Load Testing of Rock Samples
By	SF
Location	PPK Job No: 102186A
Checked	[signature]

Test Method	AS 4133.4.1 - 1993 Methods of Testing Rocks for Engineering Purposes, Determination of Point Load Strength Index
Test Machine	Engineering Laboratory Equipment
Calibration Date	15/2/00
Sampling Technique	NQ Coring
Storage History	Plastic Bags
Moisture Condition	Natural
Loading Rate	
Sampling Date	---
Testing Date	20/12/01
Tested By	SF

Rock Type	Location	Depth	Diametral Tests					Axial, Block, and Irregular Lump Tests							Strength Classification
		(m)	D (mm)	L (mm)	P (kN)	$I_{s(50)}$ (MPa)	Failure Mode	W (mm)	D (mm)	L (mm)	P (kN)	I_s (MPa)	$I_{s(50)}$ (MPa)	Failure Mode	
Sandstone - RAD(1SR)	40AE	3.8-3.96	80.8	52	1.11	0.21	Through substance	80.8	57.2	52	1.52	0.26	0.31	Through substance	L / M
Sandstone - RAD(1SR)	40AE	8.3-8.36						82.8	60.5	50	22.35	3.5	4.33	Through substance	VH
Sandstone - RAD(1SR)	40AE	10.5-10.56	82.8	50	5.82	1.07	Through substance	82.8	33.4	50	6.23	1.77	1.91	Through substance	H
Sandstone - RAD(1SR)	40AE	14.26-14.4	82.8	50	9.01	1.65	Through substance	82.8	54.7	50	13.58	2.35	2.84	Through substance	H
Sandstone - RAD(1SR)	40AW	5.09-5.21	82.4	50	3.6	0.66	Through substance	82.4	49.9	50	8.17	1.56	1.84	Through substance	M / H
Sandstone - RAD(1SR)	40AW	9.23-9.3	82.2	50	6.93	1.28	Through substance	82.2	36.8	50	4.16	1.08	1.19	Through substance	H
Quartzite - RAD(1SR)	40AW	12.55-12.7	82.9	50	9.7	1.77	Through substance	82.9	52.9	50	8.17	1.46	1.75	Through substance	H
Quartzite - RAD(1SR)	40AW	14.62-14.68	82.1	50	32.59	6.04	Through substance	82.1	43.8	50	52.43	11.45	13.12	Through substance	VH / EH
Quartzite - RAD(1SR)	40AW	14.98-15.09	82.8	50			Greater than gauge pressure (>10.37MPa)								EH
Sandstone - RAD(1SR)	52ASW	5.15-5.29	82.2	50	2.63	0.49	Through substance	82.8	37.2	50	2.77	0.71	0.78	Through substance	M
Siltstone - RAD(1SR)	52ASW	8.89-9.05	81.6	50	2.08	0.39	Through substance	81.6	52	50	2.63	0.49	0.58	Through substance	M
Siltstone - RAD(1SR)	52ASW	10.25-10.44	81.9	50	1.11	0.21	Through substance	81.9	38.6	50	2.91	0.72	0.8	Through substance	L / M
Siltstone - RAD(1SR)	52ASW	11.4-11.6	81.6	50	2.36	0.44	Through substance	81.6	54	50	3.05	0.54	0.65	Through substance	M
Siltstone - RAD(1SR)	52ASW	14.76-14.94	82	50	1.8	0.33	Through substance	82	48.4	50	2.91	0.58	0.67	Through substance	M
Siltstone - RAD(1SR)	45ASE	10.62-10.68						80.4	61.8	50	2.08	0.33	0.4	Through substance	M
Quartzite - RAD(1SR)	45ASE	7.65-7.7						82.8	54	50	21.54	3.78	4.55	Through substance	VH
Quartzite - RAD(1SR)	45ASE	12.94-13						82.6	67.2	50	22.67	3.21	4.05	Through substance	VH
Quartzite - RAD(1SR)	45ASE	14.15-14.23	82.9	50	14.17	2.59	Through substance	82.9	43.7	50	21.26	4.61	5.29	Through substance	H / VH

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Coffey Geosciences Pty Ltd ACN 056 335 516

Coffey

Point Load Strength Index Test Results

Job No	DCL3060	Sheet	2 of 2
Client	PPK - Environemt & Infrastructure	Office	Canberra
Principal		Date	20/12/01
Project	Point Load Testing of Rock Samples	By	SF
Location	PPK Job No: 102186A	Checked	[signature]

Test Method	AS 4133.4.1 - 1993 Methods of Testing Rocks for Engineering Purposes, Determination of Point Load Strength Index	Sampling Technique	NQ Coring	Sampling Date	---
Test Machine	Engineering Laboratory Equipment	Storage History	Plastic Bags	Testing Date	20/12/01
Calibration Date	15/2/00	Moisture Condition	Natural	Tested By	SF
		Loading Rate			

Rock Type	Location	Depth (m)	Diametral Tests D (mm)	L (mm)	P (kN)	$I_{s(50)}$ (MPa)	Failure Mode	Axial, Block, and Irregular Lump Tests W (mm)	D (mm)	L (mm)	P (kN)	I_s (MPa)	$I_{s(50)}$ (MPa)	Failure Mode	Strength Classification
Breccia - RAD(1SR)	52ANE	6.55-6.75	82.6	50	6.23	1.15	Through substance	82.6	67.7	50	5.96	0.84	1.06	Through substance	H
Quartzite - RAD(1SR)	52ANE	9.63-9.7						82	54	50	6.93	1.23	1.48	Through substance	H
Quartzite - RAD(1SR)	52ANE	12.3-12.39						82.6	55	50	7.09	1.22	1.48	Along defect	H
Quartzite - RAD(1SR)	52ANE	13.4-13.48	82.4	50	4.24	0.78	Along defect	82.4	46.6	50	28.34	5.8	6.74	Through substance	M / VH
Quartzite - RAD(1SR)	45ANW	6.45-6.5						82.6	59	50	14.17	2.28	2.8	Through substance	H
Quartzite - RAD(1SR)	45ANW	6.74-6.8						81	61.8	50	4.25	0.67	0.82	Through substance	M
Quartzite - RAD(1SR)	45ANW	10.83-10.9	82	50	7.09	1.32	Through substance	82	36	50	7.09	1.89	2.07	Through substance	H
Quartzite - RAD(1SR)	45ANW	14.05-14.13						82.8	43.7	50	20.55	4.46	5.12	Through substance	VH

F:\Technical\DCL30jobs\Dcl3060\[pointloadres.xls]Result Sheet (1 of 3)

Rock Description

Explanation Sheet (1 of 2)

Coffey

The descriptive terms used by Coffey are given below. They are broadly consistent with Australian Standard AS1726-1993.

DEFINITIONS: Rock substance, defect and mass are defined as follows:

Rock Substance In engineering terms rock substance is any naturally occurring aggregate of minerals and organic material which cannot be disintegrated or remoulded by hand in air or water. Other material is described using soil descriptive terms. Effectively homogonous material, may be isotropic or anisotropic.

Defect Discontinuity or break in the continuity of a substance or substances.

Mass Any body of material which is not effectively homogeneous. It can consist of two or more substances without defects, or one or more substances with one or more defects.

SUBSTANCE DESCRIPTIVE TERMS:

ROCK NAME Simple rock names are used rather than precise geological classification.

PARTICLE SIZE Grain size terms for sandstone are:

- **Coarse grained** Mainly 0.6mm to 2mm
- **Medium grained** Mainly 0.2mm to 0.6mm
- **Fine grained** Mainly 0.06mm (just visible) to 0.2mm

FABRIC Terms for layering or penetrative fabric (eg. bedding, cleavage etc.) are:

- **Massive** No layering or penetrative fabric.
- **Indistinct** Layering or fabric just visible. Little effect on properties.
- **Distinct** Layering or fabric is easily visible. Rock breaks more easily parallel to layering or fabric.

CLASSIFICATION OF WEATHERING PRODUCTS

Term	Abbreviation	Definition
Residual Soil	RS	Soil derived from the weathering of rock; the mass structure and substance fabric are no longer evident; there is a large change in volume but the soil has not been significantly transported.
Extremely Weathered Material	XW	Material is weathered to such an extent that it has soil properties, ie, it either disintegrates or can be remoulded in water. Original rock fabric still visible.
Highly Weathered Rock	HW	Rock strength is changed by weathering. The whole of the rock substance is discoloured, usually by iron staining or bleaching to the extent that the colour of the original rock is not recognisable. Some minerals are decomposed to clay minerals. Porosity may be increased by leaching or may be decreased due to the deposition of minerals in pores.
Moderately Weathered Rock	MW	The whole of the rock substance is discoloured, usually by iron staining or bleaching, to the extent that the colour of the fresh rock is no longer recognisable.
Slightly Weathered Rock	SW	Rock substance affected by weathering to the extent that partial staining or partial discolouration of the rock substance (usually by limonite) has taken place. The colour and texture of the fresh rock is recognisable; strength properties are essentially those of the fresh rock substance.
Fresh Rock	FR	Rock substance unaffected by weathering.

Notes on Weathering:

1. AS1726 suggests the term "Distinctly Weathered" (DW) to cover the range of substance weathering conditions between XW and SW. For projects where it is not practical to delineate between HW and MW or it is judged that there is no advantage in making such a distinction, DW may be used with the definition given in AS1726.

2. Where physical and chemical changes were caused by hot gasses and liquids associated with igneous rocks, the term "altered" may be substituted for "weathering" to give the abbreviations XA, HA, MA, SA and DA.

ROCK SUBSTANCE STRENGTH TERMS

Term	Abbreviation	Point Load Index, I_s50 (MPa)	Field Guide
Very Low	VL	Less than 0.1	Material crumbles under firm blows with sharp end of pick; can be peeled with a knife; pieces up to 30mm thick can be broken by finger pressure.
Low	L	0.1 to 0.3	Easily scored with a knife; indentations 1mm to 3mm show with firm blows of a pick point; has a dull sound under hammer. Pieces of core 150mm long by 50mm diameter may be broken by hand. Sharp edges of core may be friable and break during handling.
Medium	M	0.3 to 1.0	Readily scored with a knife; a piece of core 150mm long by 50mm diameter can be broken by hand with difficulty.
High	H	1 to 3	A piece of core 150mm long by 50mm can not be broken by hand but can be broken by a pick with a single firm blow; rock rings under hammer.
Very High	VH	3 to 10	Hand specimen breaks after more than one blow of a pick; rock rings under hammer.
Extremely High	EH	More than 10	Specimen requires many blows with geological pick to break; rock rings under hammer.

Notes on Rock Substance Strength:

1. In anisotropic rocks the field guide to strength applies to the strength perpendicular to the anisotropy. High strength anisotropic rocks may break readily parallel to the planar anisotropy.

2. The term "extremely low" is not used as a rock substance strength term. While the term is used in AS1726-1993, the field guide therein makes it clear that materials in that strength range are soils in engineering terms.

3. The unconfined compressive strength for isotropic rocks (and anisotropic rocks which fail across the planar anisotropy) is typically 10 to 25 times the point load index (Is50). The ratio may vary for different rock types. Lower strength rocks often have lower ratios than higher strength rocks.

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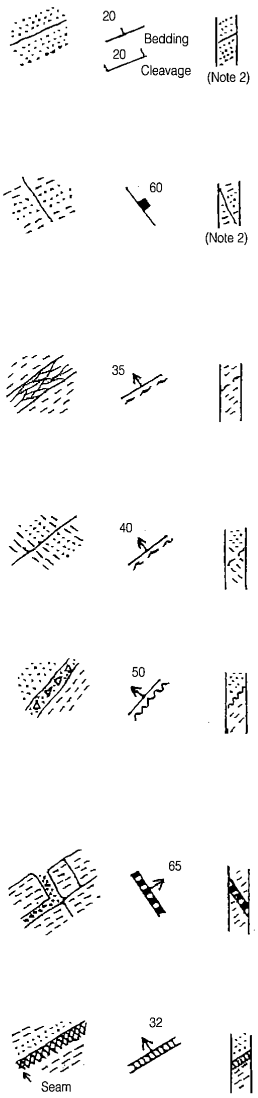
Explanation Sheet (2 of 2) – Rock Description

COMMON DEFECTS IN ROCK MASSES

Term	Definition
Parting	A surface or crack across which the rock has little or no tensile strength. Parallel or sub parallel to layering (eg bedding) or a planar anisotropy in the rock substance (eg,cleavage). May be open or closed.
Joint	A surface or crack across which the rock has little or no tensile strength but which is not parallel or sub parallel to layering or planar anisotropy in the rock substance. May be open or closed.
Sheared Zone (Note 3)	Zone of rock substance with roughly parallel near planar, curved or undulating boundaries cut by closely spaced joints, sheared surfaces or other defects. Some of the defects are usually curved and intersect to divide the mass into lenticular or wedge shaped blocks.
Sheared Surface (Note 3)	A near planar, curved or undulating surface which is usually smooth, polished or slickensided.
Crushed Seam (Note 3)	Seam with roughly parallel almost planar boundaries, composed of disoriented, usually angular fragments of the host rock substance which may be more weathered than the host rock. The seam has soil properties.
Infilled Seam	Seam of soil substance usually with distinct roughly parallel boundaries formed by the migration of soil into an open cavity or joint. Infilled seams less than 1mm thick may be described as veneer or coating on joint surface.
Extremely Weathered Seam	Seam of soil substance, often with gradational boundaries. Formed by weathering of the rock substance in place.

Diagram | Map Symbol | Graphic Log (Note 1)



Notes on Defects:
1. Usually borehole logs show the true dip of defects and face sketches and sections the apparent dip.
2. Partings and joints are not usually shown on the graphic log unless considered significant.
3. Sheared zones, sheared surfaces and crushed seams are faults in geological terms.

DEFECT SHAPE TERMS

Planar	The defect does not vary in orientation
Curved	The defect has a gradual change in orientation
Undulating	The defect has a wavy surface
Stepped	The defect has one or more well defined steps
Irregular	The defect has many sharp changes of orientation

Note: *The assessment of defect shape is partly influenced by the scale of the observation.*

ROUGHNESS TERMS

Slickensided	Grooved or striated surface, usually polished
Polished	Shiny smooth surface
Smooth	Smooth to touch. Few or no surface irregularities
Rough	Many small surface irregularities (amplitude generally less than 1mm). Feels like fine to coarse sand paper.
Very Rough	Many large surface irregularities (amplitude generally more than 1mm). Feels like, or coarser than very coarse sand paper.

COATING TERMS

Clean	No visible coating
Stained	No visible coating but surfaces are discoloured
Veneer	A visible coating of soil or mineral, too thin to measure; may be patchy
Coating	A visible coating up to 1mm thick. Thicker soil material is usually described using appropriate defect terms (eg, infilled seam). Thicker rock strength material is usually described as a vein.

BLOCK SHAPE TERMS

Blocky	Approximately equidimensional
Tabular	Thickness much less than length or width
Columnar	Height much greater than cross section

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Appendix C5
Unsaturated Zone Modelling

This appendix is a report prepared by PPK Environment & Infrastructure to model the potential impacts of the repository. A hydrogeological model was used to investigate the potential for movement of water and low level radioactive nuclide through the unsaturated zone.

C5.1 Introduction

The transport and fate of the radioactive nucleide were modelled using Chemflo 2000. Chemflo 2000 is a one-dimensional modelling package created by the Oklahoma Agricultural Research Station, in the USA (Nofziger and Wu 2001). The model is used to specifically simulate water and chemical movement through unsaturated layers of soil, but has been adapted here to simulate comparable characteristics for the rock formations at the site.

This modelling represents the second stage for evaluating potential impacts from the proposed repository. The first stage was the completion of an evaluation of the repository's design and potential for leachate generation. This design analysis has been reported under a separate report by PPK (Appendix C4 of this Draft EIS). The Chemflo modelling scenarios included one based on the indicated seepage rates from the base of the repository.

Other data used in the unsaturated zone analysis was sourced from field, meteorological and research data, and also from standard reference material.

C5.2 Site Description

The site for the focus of this assessment is Site 52a, however two other potential sites evaluated in studies by CSIRO and ANSTO (1988, 1999, 2000a,b) designated Sites 40a and 45a were also assessed under this review. The following summaries of the site characteristics are drawn from the Bureau of Rural Sciences (2001).

Site 52a is approximately 158 m above sea level at its centre and has little evident surface features to identify any surface drainage path. The site has a very gentle slope to the east (12 m over 1.5 km) and it has the smallest catchment area of all other potential sites. The site lies directly south of a formed gravel road.

Site 40a is higher in elevation, being at 189 m above sea level (as its centre) with a maximum variation in relief of 4 m over the 0.5 km inner square. This site has been identified as having the most relief of the three assessed sites. Significant features with respect to waste management are the drainage features, which may result in some surface flow being directed toward the nominated storage area.

Site 45a is the lowest of the three in elevation, being at 131 m above sea level. A broad drainage feature that runs from southeast to northwest across the site, and the Andamooka–Arcoona Road, serve to potentially concentrate rainfall runoff and direct it across the site. However the continuation of the drainage pattern indicates that runoff onto the site would continue in a northwest direction off the site.

C5.2.1 Site Geology

The generalised geology of the sites has been collated from on-site borehole data (Bureau of Rural Sciences 2001a,b). The depths and characteristics of the units summarised below (Table C5.1) have been used in the Chemflo models.

TABLE C5.1 Description of geological units in region

Depth range	Thickness	Unit	Description
Common (upper units)			
0–3.5 m	1–3 m average 1.7 m	Clay	Red, high silt low clay, sodic, sandy possibly high shrink-swell. The clays become increasingly plastic with depth.
2–8 m	0–4 m average Site 40a — 3 m Site 45a — 4 m Site 52a — 2 m*	Silcrete*	At Sites 40a and 45a: Varies in unit thickness, uniformity and hardness. Massive bands up to 30 cm thick. Basal contact with underlying formations irregular and rapid. *At Site 52a: Variously described as soft and, fractured, a loose calcrete with a fractured silcrete base or a silcrete and ferricrete base.
Common units for Site 40a and 45a beneath silcrete			
2–42 m	4–40 m, averages: 29 m (Site 40a) 21 m (Site 45a)	Simmens Quartzite	Medium to coarse grained sandstone and quartzite with inter-bedded fine-grained silt and claystone. Sand-sized beds are typically 30–40 m thick, where as the fine-grained beds are more likely to be less than 20 cm. Minor brittle fractures occur perpendicular to the bedding, with most major structural features being parallel to the bedding plane. Iron staining and silicification of the fractures is present.
24–100 m+	27–>50 m, averages: 49 m (Site 40a) Not bottomed Site 45a	Corraberra Sandstone	Harder sandstone with micaceous brown sand and siltstones altered to pug material by water. Grades with depth to darker greys and then to a light brown to chocolate interbedded sandstone/claystone. The coarsest units are cross-bedded, while the finer-grained sandstones tending to be finely laminated and horizontally bedded in all drill holes.
69–90 m+	In excess of 39 m (Site 40a)	Woomera Shale	Hard laminated fissile grey shale grading down to a puggy brown shale.
Units for Site 52a beneath silcrete			
1–27 m	6–20 m average 15 m	Bulldog shale	Typically a pale yellowish-grey massive siltstone with inter-beds of claystone, mudstone, silt and fine grained clayey sandstone. Massive beds are commonly 30–50 cm thick with clear, sharp, sub-horizontal contacts. Iron-staining is mainly weak and diffuse, particularly on bedding planes.
13–45 m	18–30 m average 22.7 m	Cadna-owie sandstone	Medium to coarse-grained sandstones interbedded with thinly bedded siltstone and mudstone. The sandstone is pinkish-white to pale pinkish-grey and consists of poorly consolidated quartzose to quartz-lithic sandstones. Core recovery was typically poor in the sandstone and this is attributed to the poor consolidation and the occurrence of cohesion-less (unconsolidated) sand beds.
38–82 m	22–37 m average 29.5 m	Corroberra sandstone	As described above
65–100 m+	Depth 66-82 m, average 69.9 m	Woomera shale	As described above

Source: Bureau of Rural Sciences (2001a,b)

C5.2.2 Site Hydrogeology

Definition of the Site Aquifers

The Corraberra Sandstone forms the regional aquifer across area of the Central–North Region of South Australia where the potential repository sites are located. The Corraberra Sandstone forms an unconfined aquifer under Sites 40a and 45a and under the southwest portion of Site 52a.

The Corraberra Sandstone is considered to be unconfined in the south western half of the buffer zone of Site 52a (termed the outer square by Bureau of Rural Sciences 2001a) and most of the inner operational zone (termed the inner drilling square (Bureau of Rural Sciences 2001a)). The remaining areas of the Corraberra Sandstone at Site 52a are considered to be semi-confined (Bureau of Rural Sciences 2001a). Site data (Bureau of Rural Sciences 2001a) shows that the watertable in this portion of Site 52a lies in the Cadna-owie Sandstone (largely at the base of this formation), overlying the Corraberra Sandstone. Airlift yields have been reported to be approximately 0.45 L/sec, indicating low permeability conditions.

A groundwater mound present in the centre area of Site 52a corresponds to where the watertable is present in the base of the Cadna-owie Sandstone. The presence of this watertable is coincident to the areas where the unconsolidated (loose) sand layers at the base of the Cadna-owie Sandstone are thickest, reportedly up to 30 cm. The mound may therefore represent local perching above the Corraberra Sandstone or upward mounding due to a local change in boundary conditions between the Corraberra and Cadna-owie Sandstones. Regardless of this, the saturated zone occurs within the intergranular pore spaces whereas outside this area of mounding the unconfined aquifer at Site 52a is the fracture zone of the Corraberra Sandstone.

Groundwater Flow Direction

Flow direction in the Corraberra Sandstone has been assessed by Bureau of Rural Sciences (2001a) as being predominantly southwest to northeast.

At Site 45a, the flow shifts to more easterly at the northern edge of the buffer zone. Groundwater flow within the Corraberra Sandstone ultimately discharges to Lake Torrens. Groundwater gradients at Site 45a range from 1:170 to 1:400. The changes in gradient corresponds to a change in measured hydraulic conductivity, indicating a more permeable zone. A lateral groundwater flow rate of 10 m/yr has been estimated on the basis of hydraulic data (Bureau of Rural Sciences 2001a).

At Site 52a the gradient is concurrent with surface topography. The watertable lies from 39–44.6 m depth, having a head drop of 10 m across the site (1.5 km) and a 'fairly uniform gradient' (Bureau of Rural Sciences 2001a) of 1:150. The groundwater flow rate has been estimated to be 20 m/year. The reviewed references (Bureau of Rural Sciences 2001a,b; CSIRO–ANSTO 1999) indicate that the formation is not hydraulically connected to the extensive aquifers of the Eromanga Basin to the west, nor is there any groundwater flow northward to the Great Artesian Basin from this area.

Groundwater Salinity

Salinity at Site 45a varies from 8000 mg/L up to 23,000 mg/L total dissolved solids (TDS). The lower salinity groundwater (8000–9000 mg/L TDS) is confined to the eastern side of this site.

The groundwater salinity at Site 40a ranges from 14,500 mg/L to 25,000 mg/L, with a median salinity of around 22,000 mg/L. The distribution of salinity is reasonable consistent, particularly for the inner area of the site.

At Site 52a salinity is homogeneous at approximately 16,000 mg/L TDS.

Recharge, Drainage and Groundwater Age

In the desert loams of the region, deep drainage at 1.5 m below non-vegetated surfaces is estimated to be only about 0.1% of annual rainfall, i.e. a range of 0.02–0.09 mm/yr (CSIRO–ANSTO 1999, 2000a,b). These values are based on gross water and chloride mass balances. Dating of groundwater indicates an age in excess of 30,000 years at Sites 45a and 52a. This suggests inconsequential recharge by modern water/rainfall.

The work completed by CSIRO and ANSTO (Bureau of Rural Sciences 2001a,b; CSIRO–ANSTO 2000a) in assessing the sites is summarised in Table C5.2.

TABLE C5.2 Summary of recharge and soil water residence times

Research methods	Recharge times	Residence times
Modelled using SWIM[(1)] at radionuclide concentration at 50 m of uniform clays and sands	0.1 mm/yr sands	Transit time to 50 m is 10^6 years.
Modelled using SWIM at radionuclide concentration at 50 m of uniform clays and sands	< 0.002 mm/yr clays	
Recharge using tracers	1–10 mm/yr and less with vegetation	
Mass balance	0.03–0.05 mm/yr	
SWIM model	Recharge = 1.5×10^{-4} cm/yr	
Chloride mass balance	~0.1% of rainfall in soil profile 0.09 mm/yr in saturated zone 0.03–0.05 mm/yr in unsaturated zone	To penetrate the 41 m of unsaturated zone it would take an estimated 14,000 years Residence time of 25-42,000 years in unsaturated zone Time to discharge to Lake Torrens estimated at 50,000 years
Used Pimba soil profile model (sodic, poor structure, surface runoff) Surface crusting (0–20 mm) Ksat = 1 mm/h to 0.01 mm/h Max conductance 0.5–1/h to min 0.005/h Soil 20–2000 mm sodic alkaline clays Ksat = 0.1 mm/h Porosity 0.45 Saturated moisture content 0.43	Recharge no vegetation 0.11 cm/yr; with vegetation 0.0001 cm/yr	Transit time to 50 m = 10^6 years
Isotope studies	Recharge only occurs after amounts of at least 80 mm in a single month for rainfall	Residence times 25–40,000 years
Water balance calculations based on the measured properties of a material very similar to the top 2 m based on average water volume fraction through the regolith of 0.2, and a porosity of at least 0.2	0.14 cm/yr if there is no vegetation	Transit time from 15 m to 40 m of approximately 3500 years

(1) Soil Water Infiltration and Movement model (Verberg et al. 1996).

C5.2.3 Geological Formation Properties

CSIRO and ANSTO completed assessment of transport characteristics for each of the geological materials present at the sites (CSIRO–ANSTO 1998, 1999, 2000a,b). The most pertinent of these are summarised below:

1. Bulldog shale:
   - retardation rates are reasonable
   - has reasonable levels of adsorption with the adsorption increasing near the bottom of the formation
2. Cadna-owie sandstone:
   - retardation rates are patchy and low
   - has lower adsorption for both cobalt and caesium
3. Corraberra sandstone:
   - retardation rates are good
   - favourable for adsorption of the studied radionuclides, presumably due to the presence of various minor phases such as mica and oxides which have good adsorption characteristics
4. Distribution coefficients measured on site samples show that:
   - trace caesium-137 is adsorbed in all profiles
   - adsorption of trace cobalt-60 is variable and depends on the clay content, pH and salt concentration
   - material from Site 52aNW 0–5 m is much more retentive of cobalt-60 than other sites.

C5.2.4 Rainfall and Storm Events

The desert area is characterised by brief storm events, followed by long periods without rainfall. The storms are generally less than a few days, with often the highest intensity rainfall occurring in only a few hours.

Rainfall data used in the modelling was from the Bureau of Meteorology, using data from Woomera. Real time historical rainfall data was used to simulate rain/storm events to assess downward percolation and transport of radionucleides within the unsaturated zone.

C5.3 Solute Transport in the Unsaturated Zone

C5.3.1 Process Overview

Solute and water transport in the unsaturated zone is complex, with the many processes still being refined and measured in the literature. Some of the principles on which Chemflo is based include:

- **Diffusion**: the movement of a chemical species in water as a result of a concentration gradient. It is a function of the charge and ionic radius of the chemical species in question. Effective diffusion, or diffusion in rock, is slowed and complicated by the pathway (tortuosity) and the porosity of the rock (available space in the rock capable of containing water) (Drever 1988).
- **Dispersion**: the mechanical movement of a solute within a rock or soil due to mechanical / hydraulic factors (Domenico and Swartz 1990).
- **Dispersivity**: is a measure of the dispersion within a soil or rock (Domenico and Swartz 1990).
- **Half-life**: the amount of time it takes a radioactive substance to be reduced to half of the initial amount, by the process of radioactive decay (Halliday and Resnick 1988).
- **Retardation**: this is the factor by which a chemical species will be retarded by the soil or rock due to factors such as sorption, compared to the rate of flow for water.

Radionuclide transport is affected by retention and retardation processes. These include filtration, adsorption, substitution, complexation, and precipitation. Figure C5.1 outlines these processes (Horseman and Volckaert 1996).

Retardation is a major influence on the movement of radionuclides through groundwater. It is measured as a factor compared to the movement of groundwater. Retardation for the species modelled was calculated from field sample distribution coefficients (Kd).

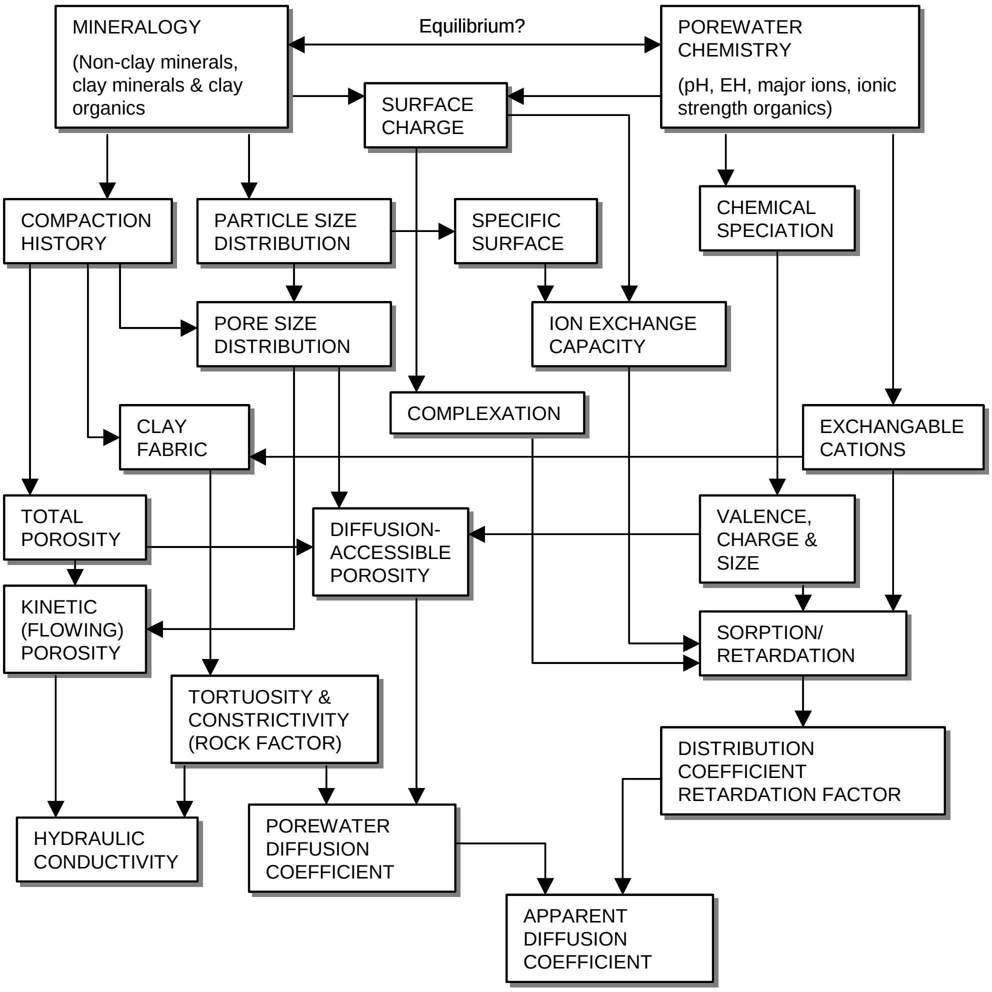

FIGURE C5.1
Diagram showing the main interactions between clay properties and radionuclide transport parameters
(Reproduced from Horseman and Volekaert 1996)

The equation for retardation is:

Retardation = 1 + (bulk density/porosity) x Kd (Drever 1988)

C5.3.2 Conceptual Site Model

The proposed repository would extend up to 15 m below surface, with the base and cap being of low permeability design (e.g. clay or engineered liner). Uncollected leachate, if generated, would therefore move through the engineered base into the underlying geological medium.

At Sites 40a and 45a, the leachate would enter the Simmens Quartzite. The watertable is encountered in the Corraberra Sandstone unit lying beneath the quartzite. The boundary between these two units is indistinct, being marked by progressively weaker silicification of the sandstone. The sequence for the profile model is therefore Simmens Quartzite and Corraberra Sandstone. At Site 40a, the watertable is some 60–65 m below surface, that is a minimum of 45 m below the base of a 15 m deep repository. Correspondingly, at Site 45a, with an unsaturated zone of 50–55 m, the base of a 15 m deep repository would be some 35–40 m below the base.

At Site 52a, watertable levels have been measured to range from 40–45 m below surface. A repository of 15 m depth would therefore have a remaining unsaturated zone of 25–30 m. This corresponds to a small thickness of Bulldog Shale possibly being present, then an average 23 m thick sequence of the Cadna-owie Sandstone being encountered and the upper Corraberra Sandstone. Depending on the site location, groundwater would be encountered within the final 30 cm of the Cadna-owie Sandstone or this upper Corraberra Sandstone.

An average value of 30 m of unsaturated zone was adopted for the modelling. For Site 52a this corresponds to modelling a multiple layered site of Bulldog Shale, Cadna-owie Sandstone and Corraberra Sandstone. At Sites 40a and 45a, this corresponds to the Simmens Quartzite and Corraberra Sandstone.

A schematic diagram of the conceptual cross section for the model is presented for Site 52a in Figure C5.2. A similar profile applies to Sites 40a and 45a.

C5.4 Chemflo Model

The Chemflo model simulates water and chemical movement through the unsaturated zone, above the watertable (Nofziger and Wu 2001). The following steps define the problem and calculate a solution:

1. Define the soil system.
2. Specify the initial conditions.
3. Specify the boundary conditions.
4. Enter transport properties of soil and chemical solution.
5. Define the mesh size.
6. Calculate the problem over specified time length for defined conditions.

C5.4.1 The Soil System

The soil system defined was called Radwaste2, and used field data for the values of:

- thickness
- hydraulic conductivity
- bulk density (for clay layer only).

The moisture content was the model default, at the lowest value accepted by the program (0.25 v/v). This however agrees with values measured by CSIRO–ANSTO in the field (Bureau of Rural Sciences 2001a). All other values (including organic carbon) were model defaults. These defaults were subject to sensitivity testing to ensure correct validation of the model. Default density values for the profile were close to those determined from site sampling. Sample test results were used in the sensitivity testing.

Details of the model profiles are presented in Attachment A.

C5.4.2 Initial Conditions

The initial conditions are the conditions for water and chemicals in the soil at the start of the simulation. For each assessment of radionuclide species, the following initial conditions were used:

- initial matrix potential (calculated from moisture content using)
- water content
- nuclide species concentration initially set to zero throughout the profile.

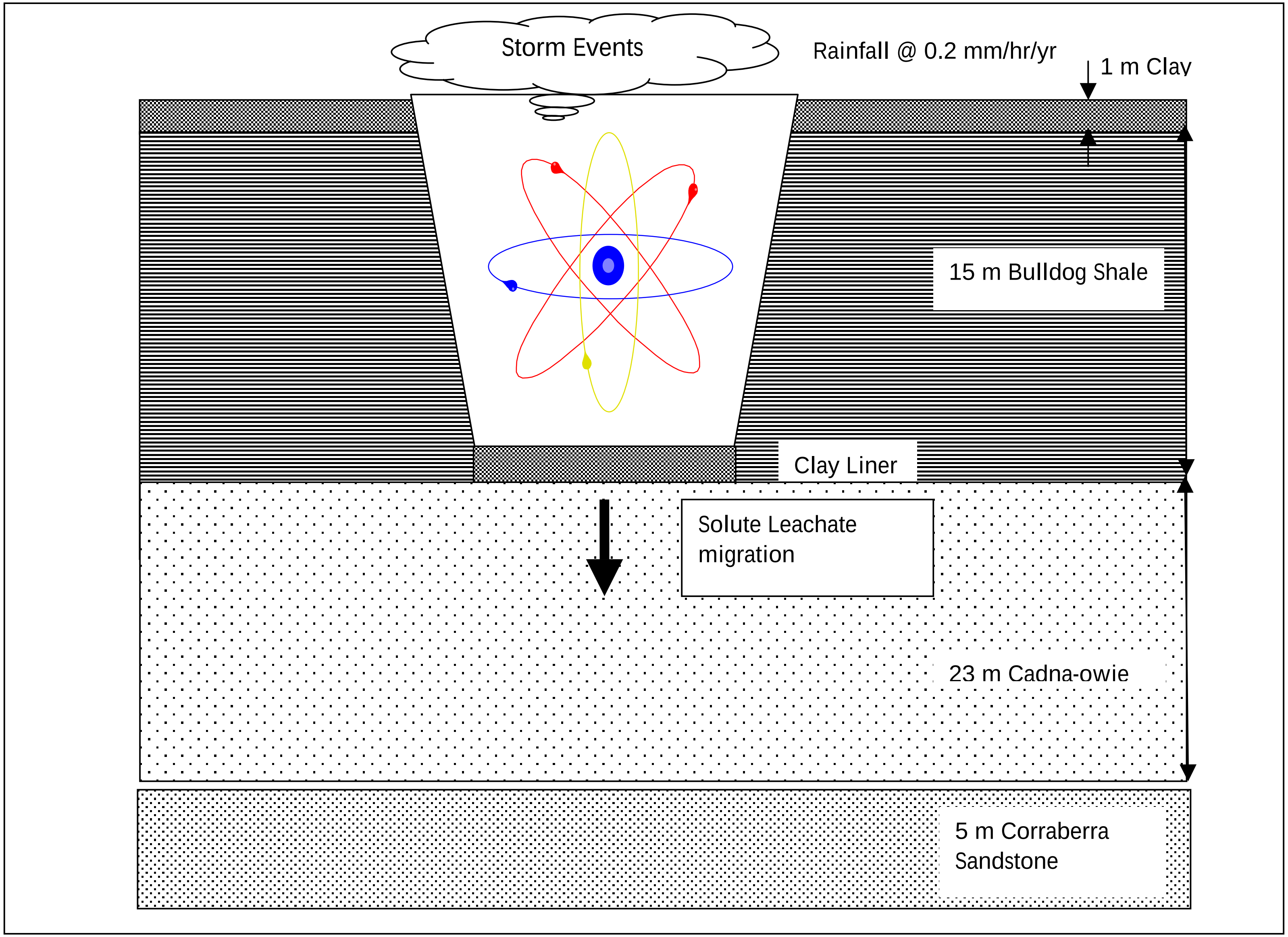

FIGURE C5.2
Conceptual Site 52a profile model

C5.4.3 Boundary Conditions

The boundary conditions are the limiting conditions on the system. For the purposes of the model, seepage (due to the repository being open) was allowed for the first 50 years. After closure, it was assumed that the engineered cap would reduce leachate to negligible amounts. In addition, it was assumed that the nuclide species would have degraded.

Accordingly the following initial conditions were set for the model:

- rainfall: 0.002 cm/h (corresponding to the average annual recharge estimate) (Bureau of Meteorology website)
- critical matrix potential: -10 000 atm
- free drainage at x = 30 m (3000 cm in the model)
- concentration of inflowing solution at x = 0 cm was 100 g/m^3.

For the second 50 years, the inflowing solution was set at zero.

C5.4.4 Transport Properties

The transport properties of the water — geological system and physio-chemical properties of the nuclide species determine the rate at which water and chemicals flow through the soil. The following transport parameters were assumed:

- a dispersivity of 0.5 cm, which is an average value from published literature (Fetter 1993)
- diffusion coefficient (from published literature) (Domenico and Swartz 1990)
- the first order degradation rate, calculated from half-life values, using the equation K+0.693/half-life (Domenico and Swartz 1990; Drever 1988).

Table C5.3 summarises the transport parameters used in the model.

TABLE C5.3 Transport properties

Property	Water	Tritium	Caesium	Cobalt
Diffusion in water, cm/h (6)	0	0.0056	0.001242	0.000423
Dispersivity of soil, cm (4)	0.5	0.5	0.5	0.5
Partition coefficient	0	0	0	0
1st order degradation constant (liquid)	0	0	0	0
1st order degradation constant (soil)	0	0.000006	2.64×10^{-11}	1.5×10^{-5}
Zero order degradation constant	0	0	0	0

Details of other physio-chemical properties for the nuclide species selected for modelling are discussed under Section C5.6 of this report.

C5.4.5 Mesh Size

This is a measure of the amount of calculations over time and space within the model. A large mesh size was used to increase the speed of the calculations.

- distance: 50 cm
- time: 24 hours
- convergence (the value applied to calculations representing acceptable error): 0.0001 (0.01%).

C5.4.6 Length of Simulation

The model was run for three difference time scenarios of:

- 50 and 100 years, at 100 g/m^3 concentration
- 50 years, at 100 g/m^3 concentration then a further 50 years at zero concentration.

C5.5 Storm Event Simulation

The averaging of yearly rainfall can give an unrealistic picture of the amount of percolation and water movement into and through the geological profile.

In order to assess worse case scenarios, a common practice to ensure a factor of safety in design, the initial simulations were completed assuming a constant rate of recharge based on an estimate of the yearly average of 0.02 mm/yr (Bureau of Rural Sciences 2001a).

However in order to assess the real word conditions and departure that may occur from the average, the effects of real rainfall/storm events was assessed using Chemflo analysis.

For these storm event simulations, storm data from the Bureau of Meteorology from Woomera was reviewed and a storm event representing the most likely event to generate wetting of the profile was selected (see Attachment B).

The simulation was run assuming 100% of the storm water rainfall penetrated the base of the repository (i.e. formed leachate).

C5.5.1 Initial Conditions

The same initial conditions as for the long-term average recharge simulations were used, with the exception of the recharge rate.

C5.5.2 Recharge Conditions

Rainfall was entered in from half-hourly storm data measured over the period 5–9 February 1997 (Bureau of Meteorology website). Before and after the storm, no recharge or inflow was allowed, that is the inflow was set as zero. Attachment B contains the storm data.

The total amount of water that fell and consequently was assumed to form recharge during the simulations were:

Simulation 1: Dry and storm phases, over 50 years (2445 hours):

- 333.5 h — nil rainfall (but an assumed 0.2 mm/h ongoing recharge)
- from 334 h to 403.5 h — total storm water: 36.8 mm
- from 403.5 h to 2445 h, nil rainfall (with an assumed ongoing recharge rate of 0.2 mm/h)
- total (non-storm) recharge at an average of 0.2 mm/h for 2445 h = 489 cm
- consequently total recharge = annual average rate + storm events = 525.8 mm.

Simulation 2: Storm event of 17 hours:

- stormwater input: 36.8 cm
- rainfall at an average of 0.2 mm/h over 17 h: 03.4 mm
- total recharge input over 17 h = 40.2 mm.

C5.5.3 Transport Properties

Tritium was selected for this analysis, as it is the most mobile nuclide species, and represents the worst case for transport.

C5.5.4 Mesh Size

These were changed to:

- distance: 0.25 cm
- time: 0.25 hours
- convergence: 0.0001.

C5.5.5 Length of Simulation

Two simulations were run using the same storm data.

The first simulation was broken down into three subsets:

- a time interval of no recharge, that is dry, which extended from over the period of the last rain event prior to 5 February 1997 as a lead into the storm event
- the storm event itself
- the follow on dry period until the next storm event.

This resulted in an overall time for simulation of 2445 hours or 101.8 days.

The second simulation used the actual storm event, recorded over a 17-hour time span.

Tritium (with the same conditions as outlined above) was re-run, with reporting intervals identical to the storm time intervals, for purposes of comparison.

C5.6 Modelled Solutes and Assumptions

The following species were modelled:

1. **Water**: this was modelled as a solution with no retardation or degradation to assess actual recharge potential (also provided a sensibility check of modelled recharge against field data indications).
2. **Tritium (H-3),** was selected as it is not significantly affected (retarded) by chemical processes, and moves with water flow (Drever 1988). However tritium does reduce relatively in concentration due to a relatively short half-life of 12.3 years.
3. **Caesium (Cs-147)** is relatively mobile (Smith et al. 1994) with a half-life of 3 x 10^6 years. It was therefore selected to represent the more persistent nuclide species. A diffusion constant for caesium was adopted from published literature (Domenico and Swartz 1990).
4. **Cobalt (Co-60)** is relatively immobile (Smith et al. 1994) with a half-life of 5.27 years. Cobalt was selected to provide a counter balance assessment of the longer half life species and also more mobile species. The diffusion constant for Co was unable to be found in published literature, so a value for Mg (magnesium), which has a similar value for ionic radius and charge, was used (Mason and Moore 1982).

C5.7 Results

C5.7.1 Site 52a

Long Term Recharge Flows

The results for the long term average annual recharge are collated in Attachment C, and tabulated in Table C5.4. Attachment D contains selected graphical representations of flow and transport outcomes generated during the modelling.

The amount of solute reaching the watertable at 30 m is indicated to be undetectable. The indicated values of concentration (as indicated in the brackets for Table C5.4) are considered to be a function of the mathematical closure of the model's numerical function as compared to real numbers. (Values of less than 2 x 10^{-24} g/m^3 represent values of less than 1 part of the mass of the earth based on an assessed mass of 6 x 10^{27} grams (Haber-Schaim et al. 1971) and an average density of 2.6 g/m^3). Hence it is sufficient to indicate that the concentrations will not exceed 1 part in 1 trillion (a million, million parts), which is lower than all but the most sensitive detection limits.

TABLE C5.4 Chemflo model results for constant recharge

Scenario	Water content (v/v)	Tritium g/m^3	Caesium g/m^3	Cobalt g/m^3
At base of repository				
Concentration after 50 yr at 100 g/m^3 inflow solution	0.25	30.4	42.0	55.9
Concentration after a further 50 yr at 100 g/m^3 inflow (i.e. total 100 yr)	0.25	28.6	39.5	50.8
Concentration after a further 50 years at zero inflow solution concentration	0.25	22.2	29.5	35.8
At 15 metres below base of repository				
Concentration after 50 yr at 100 g/m^3 inflow solution	0.082	< 10^{-12} (8 x 10^{-86})	< 10^{-12} (2 x 10^{-114})	< 10^{-12} (3 x 10^{-135})
Concentration after a further 50 yr at 100 g/m^3 inflow (i.e. total 100 yr)	0.082	< 10^{-12} (9 x 10^{-73})	< 10^{-12} (4 x 10^{-101})	< 10^{-12} (1 x 10^{-121})
Concentration after a further 50 yr at zero inflow solution concentration	0.082	< 10^{-12} (9 x 10^{-73})	< 10^{-12} (4 x 10^{-101})	< 10^{-12} (1 x 10^{-121})
At 30 metres (i.e. watertable)				
Concentration after 50 yr at 100 g/m^3 inflow solution	0.082	< 10^{-12} (9 x 10^{-179})	< 10^{-12} (3 x 10^{-227})	< 10^{-12} (6 x 10^{-262})
Concentration after a further 50 yr at zero inflow solution concentration	0.082	< 10^{-12} (2 x 10^{-156})	< 10^{-12} (9 x 10^{-205})	< 10^{-12} (2 x 10^{-239})
Concentration after 100 yr at 100 g/m^3 inflow solution	0.082	< 10^{-12} (2 x 10^{-156})	< 10^{-12} (9 x 10^{-205})	< 10^{-12} (2 x 10^{-239})

Storm Model Results

The first simulation included allowances for conditions pre and post the modelled storm events (i.e. the lead and post dry periods). Outputs from these storm simulations are tabulated in Attachment E. Representative graphs for flux density, water content and nuclide concentrations are presented in Attachment F.

The simulation showed that the soil profile at base of the repository (assumed to be open and hence the surface of the model) became saturated by the 6th hour of the rainfall event. However the wetting front from the rainfall never extended beyond 1 m during or any time after the rainfall event.

Tritium concentrations are indicated to build to around 70 g/m^3 (at a constant in put of 100 g/m^3) after approximately 12 h of the rainfall. The concentration never exceeds this value due to downward percolation and degradation. However because of the limited depth of penetration of the wetting front, the tritium is indicated to not extend beyond 1m depth (based on a detection limit of 10^{-12} g/m^3) by the end of the rainfall events. Extending the time limit for the model to 50 years confirms the lack of any further movement of detectable tritium beyond 1 m depth.

The second simulation ran for a detailed analysis of the 17-hour storm event confirms the lack of movement and hence transport of tritium beyond 1 m depth by advective soil moisture flow.

C5.7.2 Sites 40a and 45a

The modelling for Sites 40a and 45a where similar to those for Site 52a. A summary of the pertinent results is presented in Table C5.5. The values indicate that clearly the degree of movement of the nuclides is extremely limited. Adverse impact to the groundwater is indicated to not occur.

TABLE C5.5 Sites 40a and 45a results for constant recharge over 100 years

Radionuclide	Site 40a: Concentration after 100 yr at 30 m depth	Site 45a: Concentration after 100 yr at 30 m depth
Tritium	9×10^{-139}	6×10^{-137}
Caesium	2×10^{-176}	2×10^{-173}
Cobalt	3×10^{-203}	3×10^{-199}

C5.8 Sensitivity Testing and Results Validation

C5.8.1 Mesh Size (time and profile dimensions)

As the calculation uses partial differential equations to solve the problem by continuous iteration, the numerical problems are reduced to a minimum. Decreasing the mesh size of the simulation and comparing results can test these results (Nofziger and Wu 2001).

To check the sensitivity of the model due to mesh size, tritium was rerun with the mesh size reduced to 25 cm and 12 hours, half of the original dimensions. Attachment G presents the check mesh simulations with the original tritium simulation for comparison.

The results for the upper profile (0 m) show good agreement. The results at 15 m and 30 m show departures of up to one hundred orders of magnitude difference (see Table C5.6). This outcome is not considered significant however, due to the very low values being estimated, mean small departures result in seemingly large errors.

In view of the good agreement for the surface level comparisons, it is concluded that model is not sensitive to the mesh dimensions selected under this assessment.

C5.8.2 Rock Density Values

The sensitivity of the model was assessed using the Site 40a (quarzite profile) scenario. The sensitivity testing comprised re-running the model for each radionuclide with the bulk density changed from the default value of 1.55 to the laboratory determined value of 1.9.

No difference in the model outputs were observed (quartzite tritium, caesium and cobalt) between the two different densities (Attachment D). This indicates that the results were not sensitive to this parameter and the assumption of using default values has not affected the modelling outcome.

TABLE C5.6 Mesh size sensitivity analysis

Scenario	Model results (g/m^3 tritium)	Sensitivity test results (g/m^3 tritium)
At surface (0 metres)		
Concentration after 50 yr at 100 g/m^3 inflow solution	30.35	30.31
Concentration after a further 50 yr at 100g/m^3 inflow (i.e. total 100 yr)	28.62	28.59
At 15 metres		
Concentration after 50 yr at 100 g/m^3 inflow solution	8.8×10^{-86}	8.7×10^{-135}
Concentration after a further 50 yr at 100g/m^3 inflow (i.e. total 100 yr)	9×10^{-73}	7.8×10^{-114}
At 30 metres		
Concentration after 50 yr at 100 g/m^3 inflow solution	10^{-178}	1.7×10^{-298}
Concentration after a further 50 yr at zero inflow solution concentration	2×10^{-156}	2.5×10^{-259}

C5.8.3 Organic Carbon

The nature of the Chemflo model means that organic carbon can be a major parameter that affects the retardation and hence rate of movement of solute species.

The significance of this sensitivity was tested by changing the value for organic carbon. This was changed in the original Site 52a soil profile from the default 0.014 (1.4%) to 0.001 (0.1%). The latter figure is more in line with Australian conditions and deep geological conditions. Results are presented in Attachment D.

The test was completed for the scenario of tritium at a concentration of 100 g/m^3 being recharged over 100 years. As can be seen in Table C5.7, this also made no difference to the overall outcomes of the modelling. This is attributed to the limited overall migration of water (as indicated by the model) limiting the leaching potential. As a result, long travel times develop which allow the nuclide half-lives to dominant control over the remaining solute concentrations in the profile.

TABLE C5.7 Organic carbon content sensitivity testing results

Scenario	Model results (g/m^3 tritium)	Sensitivity test results (g/m^3 tritium)
At surface (0 metres)		
Concentration after a further 50 yr at 100 g/m^3 inflow (i.e. total 100 yr)	28.62	28.62
At 15 metres		
Concentration after a further 50 yr at 100 g/m^3 inflow (i.e. total 100 yr)	9×10^{-73}	9×10^{-73}
At 30 metres		
Concentration after a further 50 yr at zero inflow solution concentration	2×10^{-156}	2×10^{-156}

C5.8.4 Comparison to Overseas Waste Repository Research

The calculation of risk to the environment from the waste repository relies on the identification of all the pathways by which contaminants may flow. As stated earlier, the unsaturated zone is complicated, and more so in desert areas, since the extreme dryness brings its own level of complication.

Pathways include:

- groundwater
- vapour transport (Horseman and Volckaert 1996).

Of the two pathways, most recent research has identified vapour transport as being the most important pathway in desert areas. The work undertaken for this site using Chemflo has focussed on dissolved phase transport. Therefore consideration of the influences of the vapour phase need to be made. This is completed in a qualitative manner below.

Extensive research has occurred in the United States, with field studies and modelling for radioactive waste repositories in desert regions in Nevada. The results are applicable to Australian conditions, as the climate and rainfall patterns are quite similar.

Their results indicate the following:

1. Within the upper 13 m, measurements of water potential and temperature indicate that there is a persistent upward driving force for water, as vapour. This is consistent with deuterium and oxygen-18 isotope results.
2. Chloride mass balance calculations estimate that percolation below 10 m has been minimal or non-existent for at least 6000 to 16,000 years.

These outcomes would appear to be in accord with the estimates made by CSIRO–ANSTO for this site and the conservative estimates made for migration as dissolved phase by the Chemflo modelling.

Accordingly, this Chemflo analysis is in accord with overseas assessments, but may also be considered to be a conservative (i.e. worst case) assessment, as upward vapour movement of nuclide species would retard migration even more than has been indicated using the Chemflo model.

C5.9 Conclusion

The NHMRC 1992 Code of Practice criteria for the near surface disposal of radioactive waste (relevant to the modelling undertaken here) lists a number of criteria against which a site's suitability should be assessed. Of relevance to this assessment are the following:

1. The geological structure and hydrogeological conditions should enable prediction of radionuclide migration times and patterns.
2. The groundwater in the region of the site that may be affected by the presence of a facility should ideally have suitable geochemical and geotechnical properties to inhibit migration of radionuclides and to facilitate repository operations (NHMRC 1992).

The modeling results and the site research have indicated that all these criteria are fulfilled by Sites 40a, 45a and 52a.

The Chemflo modelling has highlighted that the low rate of recharge and geological conditions limit the risk of impact to the groundwater, and site data and modelling compared favourably with other site assessments overseas under similar conditions. These conditions, combined, result in high residence times should any leachate migration occur out of the repository, with consequential reduction of the nuclides due to radioactive decay.

C5.10 References

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C5.11 Attachment A: Geological Profile for Chemflo Model

C5.11.1 Geological Profile for Chemflo Model

Name: Radwaste2
Extent: 3000.0 cm (30 m)
Orientation: Angle of Inclination is 90.0 degrees (to the horizontal)
Properties:

Layer	Thickness (cm)	Conductivity function	Water characteristic function	Organic carbon (g/g)	Bulk density (mg/m^3)
1	100.0	vanGenuchten K_s (cm/h) = 5.4E-7 α (1/cm) = 0.019 n = 1.31	vanGenuchten θ_s (v/v) = 0.25 θ_r (v/v) = 0.095 α (1/cm) = 0.019 n = 1.31	0.014	1.28
2	100.0	vanGenuchten K_s (cm/h) = 1.56E-5 α (1/cm) = 0.015 n = 1.875	vanGenuchten θ_s (v/v) = 0.25 θ_r (v/v) = 0.08 α (1/cm) = 0.015 n = 1.875	0.014	1.55
3	2300.0	vanGenuchten K_s (cm/h) = 0.01875 α (1/cm) = 0.015 n = 1.875	vanGenuchten θ_s (v/v) = 0.25 θ_r (v/v) = 0.08 α (1/cm) = 0.015 n = 1.875	0.014	1.55
4	500.0	vanGenuchten K_s (cm/h) = 0.01875 α (1/cm) = 0.015 n = 1.875	vanGenuchten θ_s (v/v) = 0.25 θ_r (v/v) = 0.08 α (1/cm) = 0.015 n = 1.875	0.014	1.55

C5.12 Attachment B: Stormwater Data Analysis and Chemflo Inputs

Chemflo storm data, extracted from Bureau of Meteorology				
Date	**Time**	**Rain added each 0.5 h**	**Total rain**	**Chemflo intervals**
5/2/97 0:00	2:30:00 am	1	1	0.5
5/2/97 0:00	3:00:00 am	1.6	0.6	0.5
5/2/97 0:00	4:00:00 am	1.8	0.2	0.5
5/2/97 0:00	4:30:00 am	1.8	0	
5/2/97 0:00	6:00:00 am	1.8	0	
5/2/97 0:00	6:30:00 am	1.8	0	
6/2/97 0:00	1:00:00 am	0.8	-1	
6/2/97 0:00	1:30:00 am	0.8	0	
6/2/97 0:00	2:00:00 am	0.8	0	9.5
6/2/97 0:00	2:30:00 am	2	1.2	0.5
6/2/97 0:00	3:00:00 am	3.2	1.2	0.5
6/2/97 0:00	4:00:00 am	22.2	19	0.5
6/2/97 0:00	4:30:00 am	25.8	3.6	0.5
6/2/97 0:00	5:00:00 am	28.6	2.8	0.5
6/2/97 0:00	5:30:00 am	29.2	0.6	0.5
6/2/97 0:00	6:00:00 am	30.6	1.4	0.5
6/2/97 0:00	6:30:00 am	32.2	1.6	0.5
6/2/97 0:00	7:00:00 am	33.4	1.2	0.5
6/2/97 0:00	7:30:00 am	34.4	1	0.5
6/2/97 0:00	8:00:00 am	34.8	0.4	0.5
6/2/97 0:00	5:30:00 PM	0.6	0.6	0.5
6/2/97 0:00	6:00:00 PM	0.6	0	
6/2/97 0:00	6:30:00 PM	0.6	0	
6/2/97 0:00	7:00:00 PM	0.6	0	
6/2/97 0:00	7:30:00 PM	0.6	0	
6/2/97 0:00	8:00:00 PM	0.6	0	
6/2/97 0:00	8:30:00 PM	0.6	0	
6/2/97 0:00	9:00:00 PM	0.6	0	
6/2/97 0:00	9:30:00 PM	0.6	0	
6/2/97 0:00	10:00:00 PM	0.6	0	
6/2/97 0:00	10:30:00 PM	0.6	0	
6/2/97 0:00	11:00:00 PM	0.6	0	
6/2/97 0:00	11:30:00 PM	0.6	0	
7/2/97 0:00	12:00:00 am	0.6	0	
7/2/97 0:00	12:30:00 am	0.6	0	
7/2/97 0:00	1:00:00 am	0.6	0	
7/2/97 0:00	1:30:00 am	0.6	0	
7/2/97 0:00	2:00:00 am	0.6	0	
7/2/97 0:00	2:30:00 am	0.6	0	
7/2/97 0:00	3:00:00 am	0.6	0	
7/2/97 0:00	3:30:00 am	0.6	0	

Chemflo storm data, extracted from Bureau of Meteorology				
Date	Time	Rain added each 0.5 h	Total rain	Chemflo intervals
7/2/97 0:00	4:00:00 am	0.6	0	
7/2/97 0:00	4:30:00 am	0.6	0	
7/2/97 0:00	5:00:00 am	0.6	0	
7/2/97 0:00	5:30:00 am	0.6	0	
7/2/97 0:00	6:00:00 am	0.6	0	
7/2/97 0:00	6:30:00 am	0.6	0	
7/2/97 0:00	7:00:00 am	0.6	0	
7/2/97 0:00	7:30:00 am	0.6	0	
7/2/97 0:00	8:00:00 am	0.6	0	
7/2/97 0:00	11:00:00 am	0.2	-0.4	
7/2/97 0:00	11:30:00 am	0.2	0	
7/2/97 0:00	12:00:00 PM	0.2	0	
7/2/97 0:00	12:30:00 PM	0.2	0	
7/2/97 0:00	1:00:00 PM	0.2	0	
7/2/97 0:00	1:30:00 PM	0.2	0	
7/2/97 0:00	2:00:00 PM	0.2	0	
7/2/97 0:00	2:30:00 PM	0.2	0	
7/2/97 0:00	2:45:00 PM	0.2	0	
7/2/97 0:00	3:00:00 PM	0.2	0	
7/2/97 0:00	3:30:00 PM	0.2	0	
7/2/97 0:00	4:00:00 PM	0.2	0	
7/2/97 0:00	4:30:00 PM	0.2	0	
7/2/97 0:00	5:00:00 PM	0.2	0	
7/2/97 0:00	5:30:00 PM	0.2	0	
7/2/97 0:00	6:00:00 PM	0.2	0	
7/2/97 0:00	6:30:00 PM	0.2	0	
7/2/97 0:00	7:00:00 PM	0.2	0	
7/2/97 0:00	8:30:00 PM	0.2	0	
7/2/97 0:00	9:00:00 PM	0.2	0	
7/2/97 0:00	9:30:00 PM	0.2	0	
7/2/97 0:00	10:00:00 PM	0.2	0	
7/2/97 0:00	10:30:00 PM	0.2	0	
7/2/97 0:00	11:00:00 PM	0.2	0	
7/2/97 0:00	11:30:00 PM	0.2	0	
8/2/97 0:00	12:00:00 am	0.2	0	
8/2/97 0:00	12:30:00 am	0.2	0	
8/2/97 0:00	1:00:00 am	0.2	0	
8/2/97 0:00	1:30:00 am	0.2	0	
8/2/97 0:00	2:00:00 am	0.2	0	
8/2/97 0:00	2:30:00 am	0.2	0	
8/2/97 0:00	3:00:00 am	0.2	0	
8/2/97 0:00	3:30:00 am	0.2	0	
8/2/97 0:00	4:00:00 am	0.2	0	
8/2/97 0:00	4:30:00 am	0.2	0	
8/2/97 0:00	5:00:00 am	0.2	0	
8/2/97 0:00	5:30:00 am	0.2	0	
8/2/97 0:00	6:00:00 am	0.2	0	

Chemflo storm data, extracted from Bureau of Meteorology				
Date	**Time**	**Rain added each 0.5 h**	**Total rain**	**Chemflo intervals**
8/2/97 0:00	6:30:00 am	0.2	0	
8/2/97 0:00	7:00:00 am	0.2	0	
8/2/97 0:00	7:20:00 am	0.2	0	
8/2/97 0:00	7:30:00 am	0.2	0	
8/2/97 0:00	8:00:00 am	0.2	0	49.5
8/2/97 0:00	12:30:00 pm	0.4	0.2	0.5
8/2/97 0:00	1:00:00 pm	0.4	0	
8/2/97 0:00	1:30:00 pm	0.4	0	
8/2/97 0:00	2:00:00 pm	0.4	0	
8/2/97 0:00	2:30:00 pm	0.4	0	2.5
8/2/97 0:00	3:00:00 pm	0.6	0.2	0.5
8/2/97 0:00	3:30:00 pm	0.6	0	
8/2/97 0:00	4:00:00 pm	0.6	0	
8/2/97 0:00	4:30:00 pm	0.6	0	
8/2/97 0:00	5:00:00 pm	0.6	0	
8/2/97 0:00	5:30:00 pm	0.6	0	
8/2/97 0:00	6:00:00 pm	0.6	0	
8/2/97 0:00	6:30:00 pm	0.6	0	
8/2/97 0:00	7:00:00 pm	0.6	0	
8/2/97 0:00	7:30:00 pm	0.6	0	
8/2/97 0:00	8:00:00 pm	0.6	0	
8/2/97 0:00	8:30:00 pm	0.6	0	
8/2/97 0:00	9:00:00 pm	0.6	0	
8/2/97 0:00	9:30:00 pm	0.6	0	
8/2/97 0:00	10:00:00 pm	0.6	0	
8/2/97 0:00	10:30:00 pm	0.6	0	
8/2/97 0:00	11:00:00 pm	0.6	0	
8/2/97 0:00	11:30:00 pm	0.6	0	
9/2/97 0:00	12:00:00 am	0.6	0	
9/2/97 0:00	12:30:00 am	0.6	0	
9/2/97 0:00	1:00:00 am	0.6	0	
9/2/97 0:00	1:30:00 am	0.6	0	
9/2/97 0:00	2:00:00 am	0.6	0	
9/2/97 0:00	2:30:00 am	0.6	0	
9/2/97 0:00	3:00:00 am	0.6	0	
9/2/97 0:00	3:30:00 am	0.6	0	
9/2/97 0:00	4:00:00 am	0.6	0	
9/2/97 0:00	4:30:00 am	0.6	0	
9/2/97 0:00	5:00:00 am	0.6	0	
9/2/97 0:00	5:30:00 am	0.6	0	
9/2/97 0:00	6:00:00 am	0.6	0	
9/2/97 0:00	6:30:00 am	0.6	0	
9/2/97 0:00	7:00:00 am	0.6	0	
9/2/97 0:00	7:30:00 am	0.6	0	
9/2/97 0:00	8:00:00 am	0.6	0	
9/2/97 0:00	8:21:00 am	0.6	0	17

Summary

	Total rain	Time (h)	Chemflo intervals (hr)
prior to storm		333.5	333.5
	1	0.5	334
	0.6	0.5	334.5
	0.2	0.5	335
	0	9.5	344.5
	1.2	0.5	345
	1.2	0.5	345.5
	19	0.5	346
	3.6	0.5	346.5
	2.8	0.5	347
	0.6	0.5	347.5
	1.4	0.5	348
	1.6	0.5	348.5
	1.2	0.5	349
	1	0.5	349.5
	0.4	0.5	350
	0.6	0.5	350.5
	0	49.5	400
	0.2	0.5	400.5
	0	2.5	403
	0.2	0.5	403.5
	0	17	420.5
post storm		2024.5	2445

C5.13 Attachment C: Model Run Results — Annualised Leaching/Recharge Rate of 0.2 mm/yr

C5.13.1 Site 52a

Water movement run 1

Time (h)	Position (cm)	Water content
438000.0000	0.00000	0.250
438000.0000	3000.00000	0.082
876000.0000	0.00000	0.250
876000.0000	3000.00000	0.082

Tritium leaching run 1 (0–100 yr @100 mg/L inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.125	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
438000.0000	0.00000	0.250	3.035E+001
438000.0000	1500.00000	0.082	8.854E-086
438000.0000	3000.00000	0.082	9.766E-179
876000.0000	0.00000	0.250	2.862E+001
876000.0000	1500.00000	0.082	8.990E-073
876000.0000	3000.00000	0.082	1.809E-156

Tritium leaching run 2 (0–50 yr @ 100 mg/L inflow followed by 50–100 yr no inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.125	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
438000.0000	0.00000	0.250	3.035E+001
438000.0000	1500.00000	0.082	8.854E-086
438000.0000	3000.00000	0.082	9.766E-179
876000.0000	0.00000	0.250	2.220E+001
876000.0000	1500.00000	0.082	8.990E-073
876000.0000	3000.00000	0.082	1.809E-156

Tritium leaching sensitivity test 1 (0–50 yr @ 100 mg/L inflow followed by 50–100 yr no inflow) — organic carbon reduced to 0.1%

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.125	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	2.862E+001
876000.0000	1500.00000	0.082	8.990E-073
876000.0000	3000.00000	0.082	1.809E-156

Caesium leaching run 1 (0–100 yr @100 mg/L inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.125	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
438000.0000	0.00000	0.250	4.199E+001
438000.0000	1500.00000	0.082	1.469E-114
438000.0000	3000.00000	0.082	2.925E-227
876000.0000	0.00000	0.250	3.948E+001
876000.0000	1500.00000	0.082	4.151E-101
876000.0000	3000.00000	0.082	9.216E-205

Caesium leaching run 2 (0–50 yr @ 100 mg/L inflow followed by 50–100 yr no inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.125	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
438000.0000	0.00000	0.250	4.199E+001
438000.0000	1500.00000	0.082	1.469E-114
438000.0000	3000.00000	0.082	2.925E-227
876000.0000	0.00000	0.250	2.950E+001
876000.0000	1500.00000	0.082	4.151E-101
876000.0000	3000.00000	0.082	9.216E-205

Cobalt leaching run 1 (0–100 yr @100 mg/L inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.125	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
438000.0000	0.00000	0.250	5.593E+001
438000.0000	1500.00000	0.082	3.178E-135
438000.0000	3000.00000	0.082	6.027E-262
876000.0000	0.00000	0.250	5.078E+001
876000.0000	1500.00000	0.082	9.549E-122
876000.0000	3000.00000	0.082	1.871E-239

Cobalt leaching run 2 (0–50 yr @ 100 mg/L inflow followed by 50–100 yr no inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.125	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
438000.0000	0.00000	0.250	5.593E+001
438000.0000	1500.00000	0.082	3.178E-135
438000.0000	3000.00000	0.082	6.027E-262
876000.0000	0.00000	0.250	3.581E+001
876000.0000	1500.00000	0.082	9.549E-122
876000.0000	3000.00000	0.082	1.871E-239

C5.13.2 Site 45a

Tritium leaching run 1 (0–100 yr @100 mg/L inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.082	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	9.991E+001
876000.0000	1500.00000	0.082	6.470E-054
876000.0000	3000.00000	0.082	6.130E-137

Caesium leaching run 1 (0–100 yr @100 mg/L inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.082	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	1.020E+002
876000.0000	1500.00000	0.082	2.232E-068
876000.0000	3000.00000	0.082	1.604E-173

Cobalt leaching run 1 (0–100 yr @100 mg/L inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.082	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	1.034E+002
876000.0000	1500.00000	0.082	3.334E-078
876000.0000	3000.00000	0.082	3.171E-199

C5.13.3 Site 40a

Tritium leaching run 1 (0–100 yr @100 mg/L inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.082	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	9.042E+001
876000.0000	1500.00000	0.082	1.137E-058
876000.0000	3000.00000	0.082	9.111E-139

Tritium sensitivity run 1 (0–100 yr @100 mg/L inflow); bulk density of 1.9 (compared to model run 1 of 1.55)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.082	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	1.142E+002
876000.0000	1500.00000	0.082	1.477E-076
876000.0000	3000.00000	0.082	2.240E-176

Caesium leaching run 1 (0–100 yr @100 mg/L inflow)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.082	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	1.142E+002
876000.0000	1500.00000	0.082	1.477E-076
876000.0000	3000.00000	0.082	2.240E-176

Caesium sensitivity run 1 (0–100 yr @100 mg/L inflow); bulk density of 1.9 (compared to model run 1 of 1.55)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.082	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	1.142E+002
876000.0000	1500.00000	0.082	1.477E-076
876000.0000	3000.00000	0.082	2.240E-176

Cobalt leaching run 1 (0–100 yr @100 mg/L inflow)

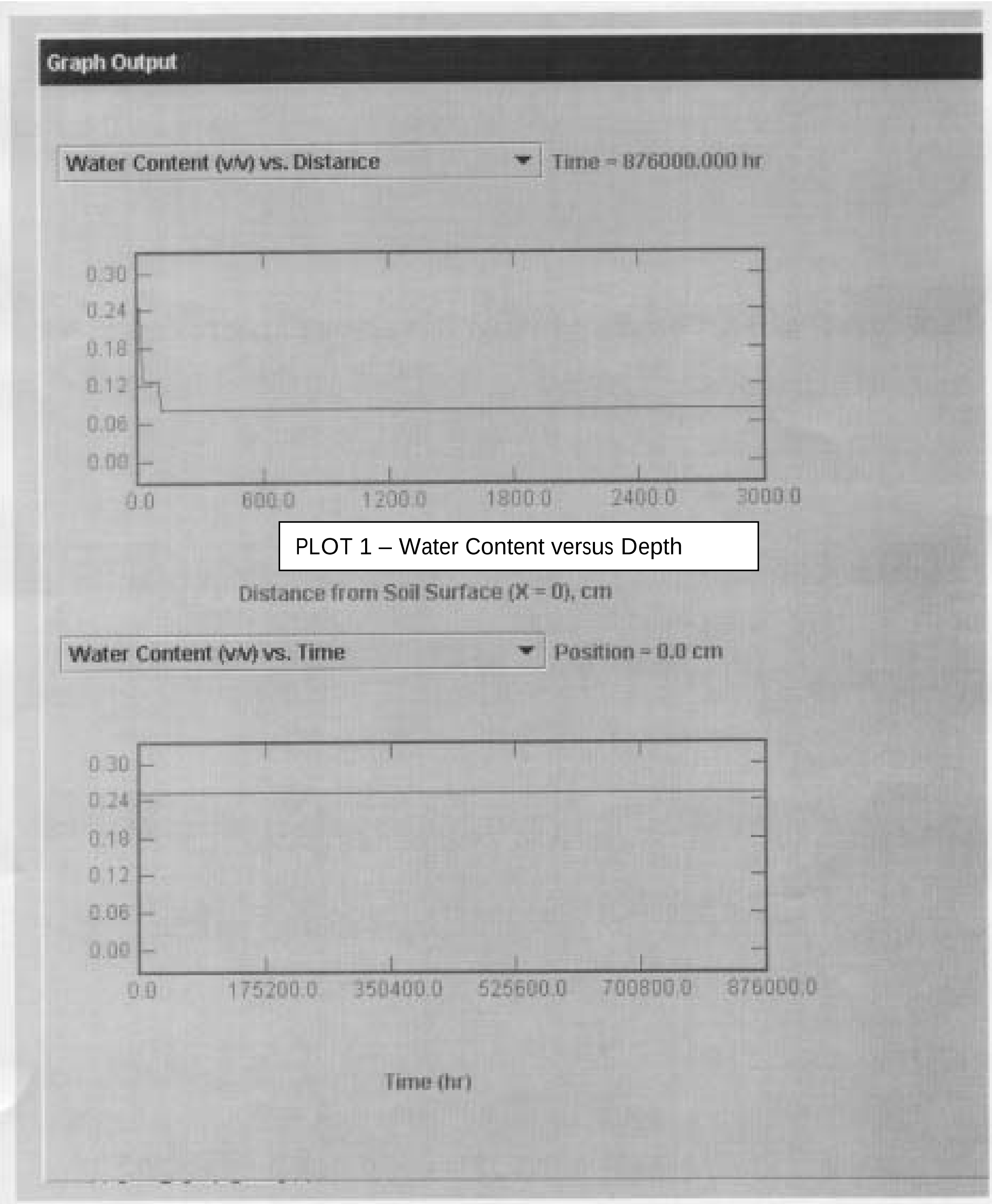
Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.082	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	1.248E+002
876000.0000	1500.00000	0.082	3.032E-089
876000.0000	3000.00000	0.082	3.739E-203

Cobalt sensitivity run 1 (0–100 yr @100 mg/L inflow); bulk density of 1.9 (compared to model run 1 of 1.55)

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)
0.0000	0.00000	0.082	0.000E+000
0.0000	1500.00000	0.082	0.000E+000
0.0000	3000.00000	0.082	0.000E+000
876000.0000	0.00000	0.250	1.248E+002
876000.0000	1500.00000	0.082	3.032E-089
876000.0000	3000.00000	0.082	3.739E-203

C5.14 Attachment D: Example of Graphical Output for Site 52

Plot 1 represents water content versus depth after 100 years of infiltration at the annualised rate of 0.2 mm/h.



PLOT 1 – Water Content versus Depth

C5.15 Attachment E: Model Run Results — Storm Event Leaching/Recharge

C5.15.1 Site 52a

Run 1 — Rainfall modelled with a lead dry period, followed by 17 hours of rainfall, followed by 50 years dry. Tritium inflow was constant at mass = 100 mg/L.

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)	Comments
0.0000	0.00000	0.125	0.000E+000	
0.0000	100.00000	0.125	0.000E+000	
0.0000	200.00000	0.082	0.000E+000	
0.0000	300.00000	0.082	0.000E+000	
0.0000	400.00000	0.082	0.000E+000	
0.0000	500.00000	0.082	0.000E+000	
0.0000	1000.00000	0.082	0.000E+000	
0.0000	1500.00000	0.082	0.000E+000	
0.0000	2000.00000	0.082	0.000E+000	
0.0000	2500.00000	0.082	0.000E+000	
0.0000	3000.00000	0.082	0.000E+000	
333.5000	0.00000	0.125	0.000E+000	
333.5000	100.00000	0.125	0.000E+000	
333.5000	200.00000	0.082	0.000E+000	
333.5000	300.00000	0.082	0.000E+000	
333.5000	400.00000	0.082	0.000E+000	
333.5000	500.00000	0.082	0.000E+000	
333.5000	1000.00000	0.082	0.000E+000	
333.5000	1500.00000	0.082	0.000E+000	
333.5000	2000.00000	0.082	0.000E+000	
333.5000	2500.00000	0.082	0.000E+000	
333.5000	3000.00000	0.082	0.000E+000	
334.0000	0.00000	0.161	4.910E+000	Rainfall commences
334.0000	100.00000	0.125	5.953E-087	
334.0000	200.00000	0.082	9.328E-184	
334.0000	300.00000	0.082	3.126E-281	
334.0000	400.00000	0.082	0.000E+000	
334.0000	500.00000	0.082	0.000E+000	
334.0000	1000.00000	0.082	0.000E+000	
334.0000	1500.00000	0.082	0.000E+000	
334.0000	2000.00000	0.082	0.000E+000	
334.0000	2500.00000	0.082	0.000E+000	
334.0000	3000.00000	0.082	0.000E+000	
334.5000	0.00000	0.173	1.089E+001	
334.5000	100.00000	0.125	3.256E-084	
334.5000	200.00000	0.082	1.975E-180	
334.5000	300.00000	0.082	1.472E-277	
334.5000	400.00000	0.082	0.000E+000	
334.5000	500.00000	0.082	0.000E+000	
334.5000	1000.00000	0.082	0.000E+000	

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)	Comments
334.5000	1500.00000	0.082	0.000E+000	
334.5000	2000.00000	0.082	0.000E+000	
334.5000	2500.00000	0.082	0.000E+000	
334.5000	3000.00000	0.082	0.000E+000	
345.0000	0.00000	0.201	1.600E+001	
345.0000	100.00000	0.125	4.231E-069	
345.0000	200.00000	0.082	2.763E-156	
345.0000	300.00000	0.082	3.878E-247	
345.0000	400.00000	0.082	0.000E+000	
345.0000	500.00000	0.082	0.000E+000	
345.0000	1000.00000	0.082	0.000E+000	
345.0000	1500.00000	0.082	0.000E+000	
345.0000	2000.00000	0.082	0.000E+000	
345.0000	2500.00000	0.082	0.000E+000	
345.0000	3000.00000	0.082	0.000E+000	
345.5000	0.00000	0.224	2.229E+001	
345.5000	100.00000	0.125	8.289E-069	
345.5000	200.00000	0.082	1.022E-155	
345.5000	300.00000	0.082	2.448E-246	
345.5000	400.00000	0.082	0.000E+000	
345.5000	500.00000	0.082	0.000E+000	
345.5000	1000.00000	0.082	0.000E+000	
345.5000	1500.00000	0.082	0.000E+000	
345.5000	2000.00000	0.082	0.000E+000	
345.5000	2500.00000	0.082	0.000E+000	
345.5000	3000.00000	0.082	0.000E+000	
346.0000	0.00000	0.250	7.141E+001	Peak rainfall
346.0000	100.00000	0.125	1.579E-068	
346.0000	200.00000	0.082	3.596E-155	
346.0000	300.00000	0.082	1.452E-245	
346.0000	400.00000	0.082	0.000E+000	
346.0000	500.00000	0.082	0.000E+000	
346.0000	1000.00000	0.082	0.000E+000	
346.0000	1500.00000	0.082	0.000E+000	
346.0000	2000.00000	0.082	0.000E+000	
346.0000	2500.00000	0.082	0.000E+000	
346.0000	3000.00000	0.082	0.000E+000	
346.5000	0.00000	0.250	7.143E+001	
346.5000	100.00000	0.125	2.930E-068	
346.5000	200.00000	0.082	1.209E-154	
346.5000	300.00000	0.082	8.117E-245	
346.5000	400.00000	0.082	0.000E+000	
346.5000	500.00000	0.082	0.000E+000	
346.5000	1000.00000	0.082	0.000E+000	
346.5000	1500.00000	0.082	0.000E+000	
346.5000	2000.00000	0.082	0.000E+000	
346.5000	2500.00000	0.082	0.000E+000	
346.5000	3000.00000	0.082	0.000E+000	
347.0000	0.00000	0.250	7.144E+001	
347.0000	100.00000	0.125	5.308E-068	

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)	Comments
347.0000	200.00000	0.082	3.893E-154	
347.0000	300.00000	0.082	4.296E-244	
347.0000	400.00000	0.082	0.000E+000	
347.0000	500.00000	0.082	0.000E+000	
347.0000	1000.00000	0.082	0.000E+000	
347.0000	1500.00000	0.082	0.000E+000	
347.0000	2000.00000	0.082	0.000E+000	
347.0000	2500.00000	0.082	0.000E+000	
347.0000	3000.00000	0.082	0.000E+000	
347.5000	0.00000	0.250	7.146E+001	
347.5000	100.00000	0.125	9.407E-068	
347.5000	200.00000	0.082	1.204E-153	
347.5000	300.00000	0.082	2.159E-243	
347.5000	400.00000	0.082	0.000E+000	
347.5000	500.00000	0.082	0.000E+000	
347.5000	1000.00000	0.082	0.000E+000	
347.5000	1500.00000	0.082	0.000E+000	
347.5000	2000.00000	0.082	0.000E+000	
347.5000	2500.00000	0.082	0.000E+000	
347.5000	3000.00000	0.082	0.000E+000	End of peak rainfall
348.0000	0.00000	0.250	7.147E+001	
348.0000	100.00000	0.125	1.633E-067	
348.0000	200.00000	0.082	3.587E-153	
348.0000	300.00000	0.082	1.033E-242	
348.0000	400.00000	0.082	0.000E+000	
348.0000	500.00000	0.082	0.000E+000	
348.0000	1000.00000	0.082	0.000E+000	
348.0000	1500.00000	0.082	0.000E+000	
348.0000	2000.00000	0.082	0.000E+000	
348.0000	2500.00000	0.082	0.000E+000	
348.0000	3000.00000	0.082	0.000E+000	
348.5000	0.00000	0.250	7.148E+001	
348.5000	100.00000	0.125	2.781E-067	
348.5000	200.00000	0.082	1.032E-152	
348.5000	300.00000	0.082	4.717E-242	
348.5000	400.00000	0.082	0.000E+000	
348.5000	500.00000	0.082	0.000E+000	
348.5000	1000.00000	0.082	0.000E+000	
348.5000	1500.00000	0.082	0.000E+000	
348.5000	2000.00000	0.082	0.000E+000	
348.5000	2500.00000	0.082	0.000E+000	
348.5000	3000.00000	0.082	0.000E+000	
349.0000	0.00000	0.250	7.150E+001	
349.0000	100.00000	0.125	4.651E-067	
349.0000	200.00000	0.082	2.870E-152	
349.0000	300.00000	0.082	2.063E-241	
349.0000	400.00000	0.082	0.000E+000	
349.0000	500.00000	0.082	0.000E+000	
349.0000	1000.00000	0.082	0.000E+000	
349.0000	1500.00000	0.082	0.000E+000	

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)	Comments
349.0000	2000.00000	0.082	0.000E+000	
349.0000	2500.00000	0.082	0.000E+000	
349.0000	3000.00000	0.082	0.000E+000	
349.5000	0.00000	0.250	7.151E+001	
349.5000	100.00000	0.125	7.650E-067	
349.5000	200.00000	0.082	7.740E-152	
349.5000	300.00000	0.082	8.651E-241	
349.5000	400.00000	0.082	0.000E+000	
349.5000	500.00000	0.082	0.000E+000	
349.5000	1000.00000	0.082	0.000E+000	
349.5000	1500.00000	0.082	0.000E+000	
349.5000	2000.00000	0.082	0.000E+000	
349.5000	2500.00000	0.082	0.000E+000	
349.5000	3000.00000	0.082	0.000E+000	
350.0000	0.00000	0.250	7.153E+001	
350.0000	100.00000	0.125	1.239E-066	
350.0000	200.00000	0.082	2.026E-151	
350.0000	300.00000	0.082	3.489E-240	
350.0000	400.00000	0.082	0.000E+000	
350.0000	500.00000	0.082	0.000E+000	
350.0000	1000.00000	0.082	0.000E+000	
350.0000	1500.00000	0.082	0.000E+000	
350.0000	2000.00000	0.082	0.000E+000	
350.0000	2500.00000	0.082	0.000E+000	
350.0000	3000.00000	0.082	0.000E+000	
350.5000	0.00000	0.250	7.154E+001	
350.5000	100.00000	0.125	1.976E-066	
350.5000	200.00000	0.082	5.160E-151	
350.5000	300.00000	0.082	1.355E-239	
350.5000	400.00000	0.082	0.000E+000	
350.5000	500.00000	0.082	0.000E+000	
350.5000	1000.00000	0.082	0.000E+000	
350.5000	1500.00000	0.082	0.000E+000	
350.5000	2000.00000	0.082	0.000E+000	
350.5000	2500.00000	0.082	0.000E+000	
350.5000	3000.00000	0.082	0.000E+000	
400.0000	0.00000	0.250	7.266E+001	
400.0000	100.00000	0.125	4.939E-056	
400.0000	200.00000	0.082	4.159E-132	
400.0000	300.00000	0.082	8.920E-212	
400.0000	400.00000	0.082	2.187E-288	
400.0000	500.00000	0.082	0.000E+000	
400.0000	1000.00000	0.082	0.000E+000	
400.0000	1500.00000	0.082	0.000E+000	
400.0000	2000.00000	0.082	0.000E+000	
400.0000	2500.00000	0.082	0.000E+000	
400.0000	3000.00000	0.082	0.000E+000	
400.5000	0.00000	0.250	7.267E+001	
400.5000	100.00000	0.125	5.659E-056	
400.5000	200.00000	0.082	5.383E-132	

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)	Comments
400.5000	300.00000	0.082	1.276E-211	
400.5000	400.00000	0.082	3.487E-288	
400.5000	500.00000	0.082	0.000E+000	
400.5000	1000.00000	0.082	0.000E+000	
400.5000	1500.00000	0.082	0.000E+000	
400.5000	2000.00000	0.082	0.000E+000	
400.5000	2500.00000	0.082	0.000E+000	
400.5000	3000.00000	0.082	0.000E+000	
403.5000	0.00000	0.250	7.273E+001	
403.5000	100.00000	0.125	1.249E-055	
403.5000	200.00000	0.082	2.449E-131	
403.5000	300.00000	0.082	1.039E-210	
403.5000	400.00000	0.082	5.335E-287	
403.5000	500.00000	0.082	0.000E+000	
403.5000	1000.00000	0.082	0.000E+000	
403.5000	1500.00000	0.082	0.000E+000	
403.5000	2000.00000	0.082	0.000E+000	
403.5000	2500.00000	0.082	0.000E+000	
403.5000	3000.00000	0.082	0.000E+000	Rainfall ceases
2445.0000	0.00000	0.250	7.450E+001	
2445.0000	100.00000	0.125	2.211E-032	
2445.0000	200.00000	0.082	2.459E-083	
2445.0000	300.00000	0.082	1.103E-138	
2445.0000	400.00000	0.082	9.215E-193	
2445.0000	500.00000	0.082	3.507E-252	
2445.0000	1000.00000	0.082	0.000E+000	
2445.0000	1500.00000	0.082	0.000E+000	
2445.0000	2000.00000	0.082	0.000E+000	
2445.0000	2500.00000	0.082	0.000E+000	
2445.0000	3000.00000	0.082	0.000E+000	

Run 2 — Detailed analysis of migration after 17 hours rainfall with the peak fall at 12.5 hours. Tritium input is at a constant 100 mg/L.

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)	Comments
0.0000	0.00000	0.125	0.000E+000	
0.0000	100.00000	0.125	0.000E+000	
0.0000	200.00000	0.082	0.000E+000	
0.0000	300.00000	0.082	0.000E+000	
0.0000	400.00000	0.082	0.000E+000	
0.0000	500.00000	0.082	0.000E+000	
0.0000	1000.00000	0.082	0.000E+000	
0.0000	3000.00000	0.082	0.000E+000	
0.5000	0.00000	0.161	9.722E+000	
0.5000	100.00000	0.125	2.173E-085	
0.5000	200.00000	0.082	6.625E-182	
0.5000	300.00000	0.082	3.299E-279	
0.5000	400.00000	0.082	0.000E+000	
0.5000	500.00000	0.082	0.000E+000	

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)	Comments
0.5000	1000.00000	0.082	0.000E+000	
0.5000	3000.00000	0.082	0.000E+000	
1.0000	0.00000	0.173	1.527E+001	
1.0000	100.00000	0.125	4.154E-083	
1.0000	200.00000	0.082	4.789E-179	
1.0000	300.00000	0.082	5.265E-276	
1.0000	400.00000	0.082	0.000E+000	
1.0000	500.00000	0.082	0.000E+000	
1.0000	1000.00000	0.082	0.000E+000	
1.0000	3000.00000	0.082	0.000E+000	
1.5000	0.00000	0.176	1.754E+001	
1.5000	100.00000	0.125	2.412E-081	
1.5000	200.00000	0.082	1.042E-176	
1.5000	300.00000	0.082	2.525E-273	
1.5000	400.00000	0.082	0.000E+000	
1.5000	500.00000	0.082	0.000E+000	
1.5000	1000.00000	0.082	0.000E+000	
1.5000	3000.00000	0.082	0.000E+000	
11.0000	0.00000	0.176	1.750E+001	
11.0000	100.00000	0.125	4.651E-069	
11.0000	200.00000	0.082	2.003E-156	
11.0000	300.00000	0.082	2.026E-247	
11.0000	400.00000	0.082	0.000E+000	
11.0000	500.00000	0.082	0.000E+000	
11.0000	1000.00000	0.082	0.000E+000	
11.0000	3000.00000	0.082	0.000E+000	
11.5000	0.00000	0.201	1.961E+001	
11.5000	100.00000	0.125	9.296E-069	
11.5000	200.00000	0.082	7.650E-156	
11.5000	300.00000	0.082	1.329E-246	
11.5000	400.00000	0.082	0.000E+000	
11.5000	500.00000	0.082	0.000E+000	
11.5000	1000.00000	0.082	0.000E+000	
11.5000	3000.00000	0.082	0.000E+000	
12.0000	0.00000	0.224	2.542E+001	
12.0000	100.00000	0.125	1.804E-068	
12.0000	200.00000	0.082	2.775E-155	
12.0000	300.00000	0.082	8.176E-246	
12.0000	400.00000	0.082	0.000E+000	
12.0000	500.00000	0.082	0.000E+000	
12.0000	1000.00000	0.082	0.000E+000	
12.0000	3000.00000	0.082	0.000E+000	
12.5000	0.00000	0.250	7.358E+001	Peak rainfall commences (maximum rate 35 mm in 0.5 h)
12.5000	100.00000	0.125	3.405E-068	
12.5000	200.00000	0.082	9.597E-155	
12.5000	300.00000	0.082	4.733E-245	
12.5000	400.00000	0.082	0.000E+000	
12.5000	500.00000	0.082	0.000E+000	
12.5000	1000.00000	0.082	0.000E+000	

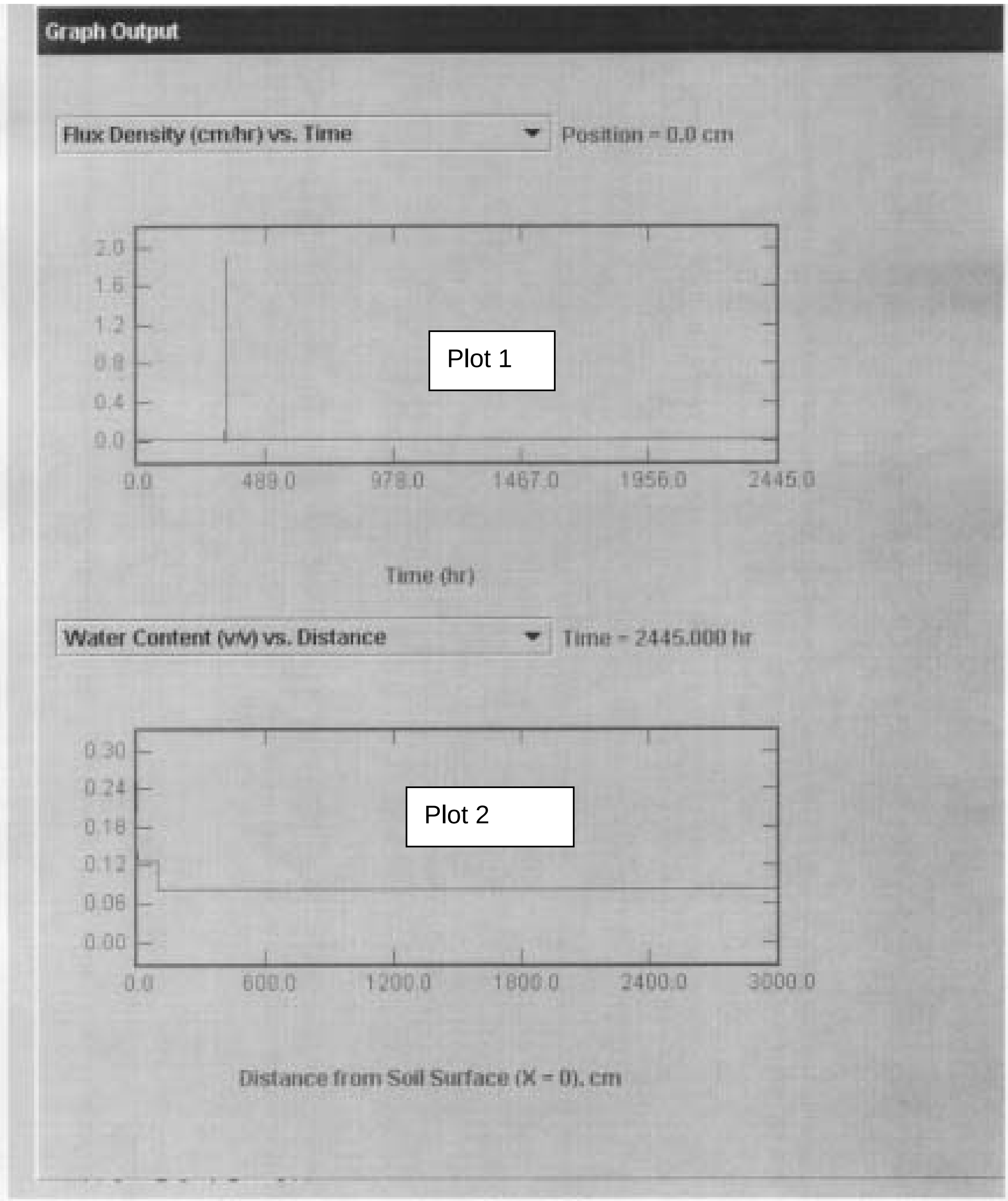
Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)	Comments
12.5000	3000.00000	0.082	0.000E+000	
13.0000	0.00000	0.250	7.359E+001	
13.0000	100.00000	0.125	6.269E-068	
13.0000	200.00000	0.082	3.173E-154	
13.0000	300.00000	0.082	2.588E-244	
13.0000	400.00000	0.082	0.000E+000	
13.0000	500.00000	0.082	0.000E+000	
13.0000	1000.00000	0.082	0.000E+000	
13.0000	3000.00000	0.082	0.000E+000	
13.5000	0.00000	0.250	7.361E+001	
13.5000	100.00000	0.125	1.128E-067	
13.5000	200.00000	0.082	1.006E-153	
13.5000	300.00000	0.082	1.341E-243	
13.5000	400.00000	0.082	0.000E+000	
13.5000	500.00000	0.082	0.000E+000	
13.5000	1000.00000	0.082	0.000E+000	
13.5000	3000.00000	0.082	0.000E+000	
14.0000	0.00000	0.250	7.362E+001	
14.0000	100.00000	0.125	1.985E-067	
14.0000	200.00000	0.082	3.069E-153	
14.0000	300.00000	0.082	6.606E-243	
14.0000	400.00000	0.082	0.000E+000	
14.0000	500.00000	0.082	0.000E+000	
14.0000	1000.00000	0.082	0.000E+000	
14.0000	3000.00000	0.082	0.000E+000	
14.5000	0.00000	0.250	7.363E+001	
14.5000	100.00000	0.125	3.424E-067	
14.5000	200.00000	0.082	9.024E-153	
14.5000	300.00000	0.082	3.102E-242	
14.5000	400.00000	0.082	0.000E+000	
14.5000	500.00000	0.082	0.000E+000	
14.5000	1000.00000	0.082	0.000E+000	
14.5000	3000.00000	0.082	0.000E+000	
15.0000	0.00000	0.250	7.365E+001	
15.0000	100.00000	0.125	5.796E-067	
15.0000	200.00000	0.082	2.564E-152	
15.0000	300.00000	0.082	1.393E-241	
15.0000	400.00000	0.082	0.000E+000	
15.0000	500.00000	0.082	0.000E+000	
15.0000	1000.00000	0.082	0.000E+000	
15.0000	3000.00000	0.082	0.000E+000	
15.5000	0.00000	0.250	7.366E+001	
15.5000	100.00000	0.125	9.643E-067	
15.5000	200.00000	0.082	7.051E-152	
15.5000	300.00000	0.082	5.990E-241	
15.5000	400.00000	0.082	0.000E+000	
15.5000	500.00000	0.082	0.000E+000	
15.5000	1000.00000	0.082	0.000E+000	
15.5000	3000.00000	0.082	0.000E+000	
16.0000	0.00000	0.250	7.367E+001	

Time (h)	Position (cm)	Water content	Concentration solution (g/m^3)	Comments
16.0000	100.00000	0.125	1.578E-066	
16.0000	200.00000	0.082	1.881E-151	
16.0000	300.00000	0.082	2.474E-240	
16.0000	400.00000	0.082	0.000E+000	
16.0000	500.00000	0.082	0.000E+000	
16.0000	1000.00000	0.082	0.000E+000	
16.0000	3000.00000	0.082	0.000E+000	
16.5000	0.00000	0.250	7.369E+001	
16.5000	100.00000	0.125	2.543E-066	
16.5000	200.00000	0.082	4.875E-151	
16.5000	300.00000	0.082	9.831E-240	
16.5000	400.00000	0.082	0.000E+000	
16.5000	500.00000	0.082	0.000E+000	
16.5000	1000.00000	0.082	0.000E+000	
16.5000	3000.00000	0.082	0.000E+000	
17.0000	0.00000	0.250	7.370E+001	
17.0000	100.00000	0.125	4.039E-066	
17.0000	200.00000	0.082	1.230E-150	
17.0000	300.00000	0.082	3.767E-239	
17.0000	400.00000	0.082	4.941E-324	
17.0000	500.00000	0.082	0.000E+000	
17.0000	1000.00000	0.082	0.000E+000	
17.0000	3000.00000	0.082	0.000E+000	

C5.16 Attachment F: Graphical Output for Site 52 Analysis — Storm Simulation

Plot 1 shows the flux of moisture that is generated by the storm event, with a peak inflow occurring around 300–400 hours after simulation commences. This is line with the real time storm data.

Storm simulation

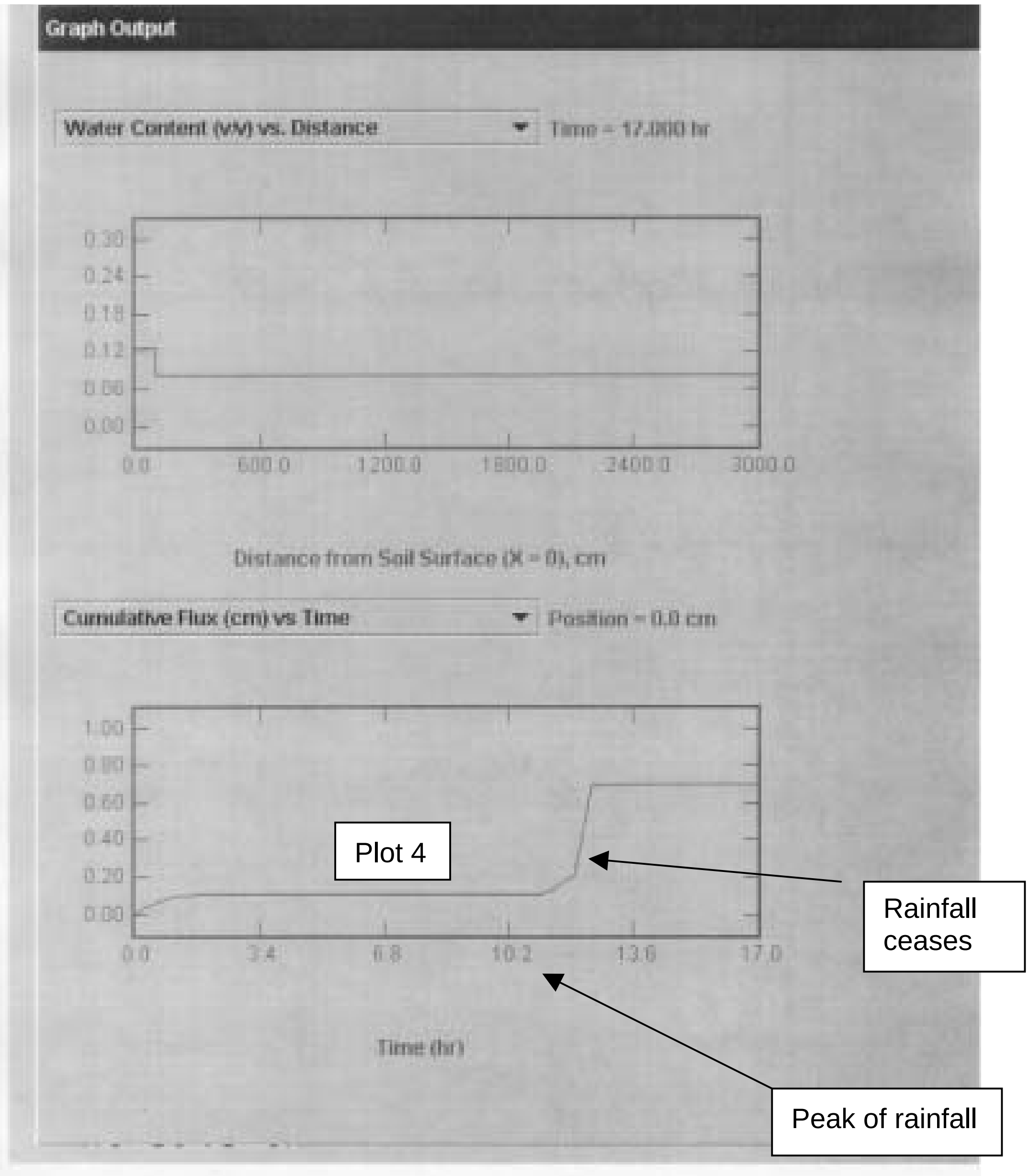


The peak nature of the response shows lack of residual flux movement after the rainfall event. This means there is little movement of the moisture after entering the system.

Plot 2 highlights this lack of movement, showing that after the 50-year period, the soil profile has been wetted (i.e. above the residual moisture content or dry soil content) to a fraction of the depth of the 30 m profile. The plot indicates the wetting front to have advanced approximately 100 cm (1 m) from the base of assumed surface (in this case the base of the repository).

Plot 4 (below) visually displays the rainfall flux (i.e. input) with time. At 11 hours the rainfall rate increases with a corresponding increase in flux. This peaks at 12 hours, and then rainfall ceases.

17-hour storm event



Total rainfall input is of the order of 70 mm.

C5.17 Attachment G: Model Mesh Size Sensitivity Analysis

Mesh sensitivity testing was completed by adjusting the layers in the model from 50 cm to 25 cm and the time steps from 24 hours to 12 hours.

Inflow of tritium was constant at 100 mg/L (g/m^3). The table below shows the comparison between the original Site 52a analysis for tritium with 100 years inflow and the adjusted mesh inputs.

Time (h)	Position (cm)	Primary model result (g/m^3)	Mesh size sensitivity result (g/m^3)
0.0000	0.00000	0.000E+000	0.000E+000
0.0000	1500.00000	0.000E+000	0.000E+000
0.0000	3000.00000	0.000E+000	0.000E+000
438000.0000	0.00000	3.035E+001	3.031E+001
438000.0000	1500.00000	8.854E-086	8.669E-135
438000.0000	3000.00000	9.766E-179	1.676E-298
876000.0000	0.00000	2.862E+001	2.859E+001
876000.0000	1500.00000	8.990E-073	7.775E-114
876000.0000	3000.00000	1.809E-156	2.468E-259

APPENDIX D

Appendix D

BIOLOGICAL ENVIRONMENT

D1 Flora

Badman Environmental

D2 Fauna

Halliburton KBR

D

Appendix D1
Flora

This appendix is a report which provides the background information for the flora information presented in Chapter 9. The information is based on a flora survey conducted in August 2001.

D1.1 Introduction

This report forms part of the baseline environmental studies for use in the selection of a permanent site for the national repository. The field survey was carried out during August 2001 and covered three potential sites near Woomera. It was designed to fulfil two objectives:

1. Be a baseline survey against which future surveys can be used to detect any changes to the vegetation that may result from activities connected with the repository site.
2. Collect quantitative data on the vegetation of the area that could be examined by means of multivariate analysis techniques to compare these data to themselves and to other data collected from the Arcoona Tableland. Classification of the data would show whether any parts of the site(s) are significantly different from the remainder of the site(s) and from other areas on the Arcoona Tableland.

D1.1.1 Study Area

Location

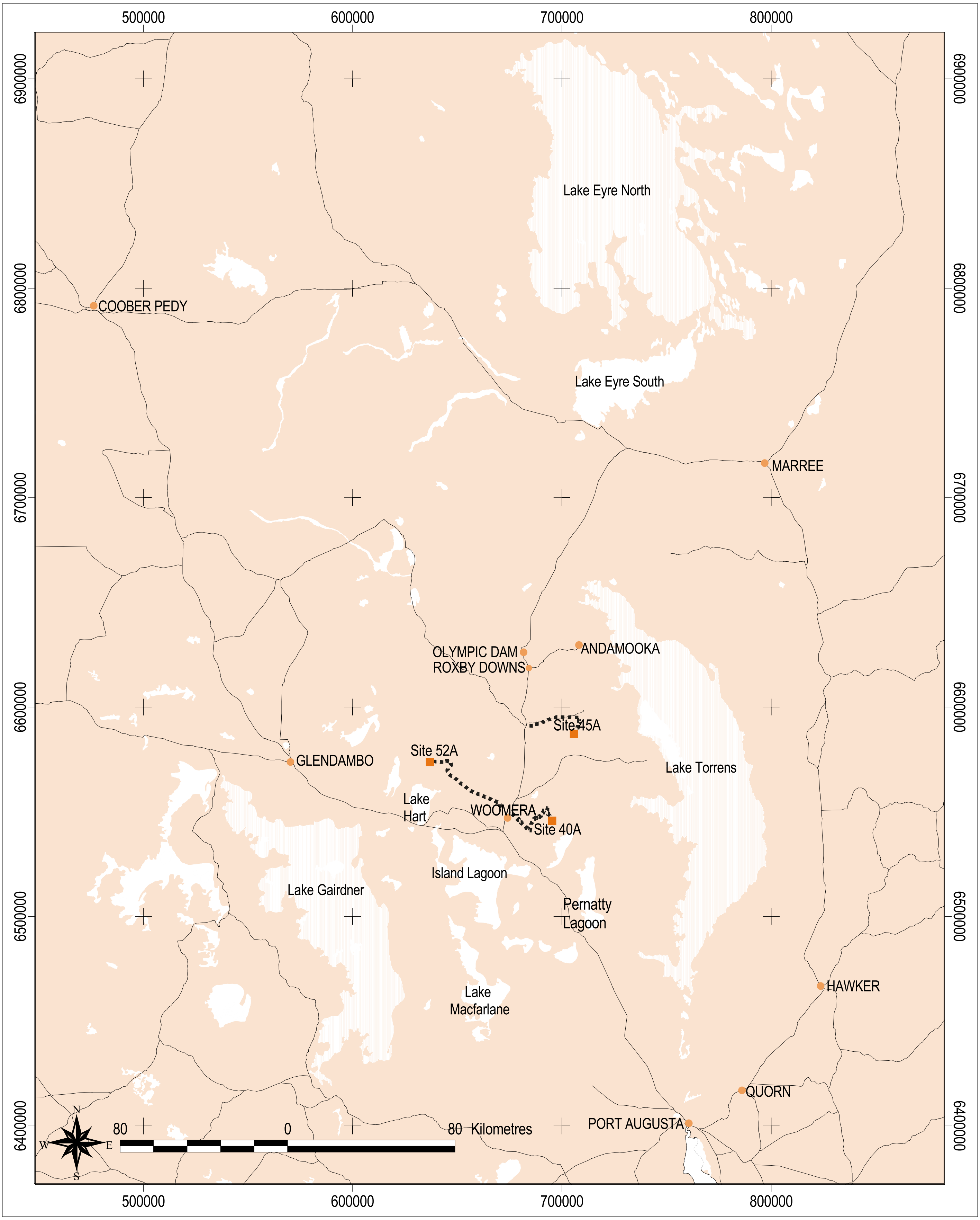
The three potential sites are located on the Arcoona Tableland (Figure D1.1). The surveyed sites are Site 40a, located approximately 21 km east of Woomera on Arcoona Station, Site 45a, located approximately 51 km northeast of Woomera on Andamooka Station, and Site 52a, located approximately 7 km west of Koolymilka. Koolymilka is 40 km northwest of Woomera and is within the Woomera Prohibited Area. For example photographs of flora quadrats see Figures D1.2, D1.3 and D1.4.

Regional Setting

The Arcoona Tableland is a mostly treeless plain, with vegetation dominated by chenopod low shrubland that is less than one metre in height. The densest vegetation occurs in the gilgais[1] that are a common feature of the tableland. The few trees that do occur here often grow in small clumps or colonies. No trees are present at any of the three survey sites.

Laut et al. (1977) placed the Arcoona Tableland in the Woomera Environmental Association, although it must be emphasised that their classification was not concerned primarily with vegetation. The Arcoona Tableland was recognised as forming a distinct land system, the Arcoona land system, by McDonald (1992), Kingoonya Soil Conservation Board (1996) and Badman (2001). These classifications placed greater emphasis on vegetation but still took account of landform. Vegetation of the Arcoona land system has similarities with several other gibber plain land systems that occur in the region (Badman 2001). These are principally the Oodnadatta, Paisley and Breakaway land systems to the northwest, although some minor parts of the Ebunbanie land system, which occurs to the southwest, also have similar vegetation.

[1] Gilgais are the micro-relief of soils produced by expansion and contraction through changes in soil moisture. They are found in soils that contain large amounts of clay. Gilgais are characterised by a markedly undulating surface with mounds (shelves) and depressions that collect runoff water from the shelves. They are often referred to locally as 'crab holes'.



Towns
Potential Repository Sites
Roads
Salt Lakes
Access tracks

Figure D1.1

Potential Repository Sites

Classification of the Kingoonya Soil Conservation District dataset (Badman 2001) using the PATN analysis package (Belbin 1992) showed that when compared to data from more than 400 sites in other local land systems, only two of the 20 Arcoona Tableland sites did not fall within the main vegetation group. In addition, vegetation from 16 sites in other land systems was also included in this group.

Seasonal Conditions

Seasonal conditions at the time of the August 2001 survey were excellent. Good general rains of 75–100 mm fell across the whole of the Arcoona Tableland during late May and early June 2001. Despite a slow growth response because of cold weather during the first weeks following the rain, warm weather during late July and early August produced significant plant growth and most species were in flower and readily identifiable at the time of the survey. Several species were recorded that had not been seen in the district since the exceptional rainfall events of 1989.

D1.1.2 Approach

The vegetation study was handled in three parts:

- A preliminary desktop study to examine existing data from published and unpublished sources: quantitative data that could be used for direct comparisons with the present survey data include Badman's unpublished data, data from the State Government's Stony Deserts Biological Survey (Brandle 1998), and data collected during a recent review of the land systems of the Kingoonya Soil Conservation District (Badman 2001). Historical data were also checked for the presence of any species that are listed on federal or State conservation schedules and that may be expected to occur on the Arcoona Tableland.
- A field survey in August 2001 of the three potential sites, when quantitative data were collected on species composition and abundance: 13 areas were sampled at each site: one in the centre; four opposite the mid-point of the 500 m square around the centre of the site and half way to the 1500 m outside square; one about 150–200 m inside each of the site corners; and one located a similar distance outside each site corner. Photographs were taken at each site and the alignment bearing of each photograph was recorded so they could be replicated as part of a future-monitoring program. Plants that could not be positively identified in the field were collected and later identified at the State Herbarium of South Australia. The field survey also looked at potential impacts that could be caused by the widening of access tracks and the construction of security and/or boundary fences.
- Entry of field data into an Excel spreadsheet and analysis using the CSIRO PATN analysis program: data from the field survey were compared against themselves, against data collected during the Stony Deserts Biological Survey (Brandle 1998) and against data collected during the Kingoonya Soil Conservation District land systems survey (Badman 2001).

D1.2 Literature Review

D1.2.1 Overview

Willis (1981) and Kraehenbuehl (1986) gave a general overview of the history of botanical research in the study area. One of the first publications to mention the plants of the Arcoona Tableland region was that of Cleland (1930) who travelled from Chances Swamp (Roxby Downs HS) to Andamooka. Murray (1931) gave a more comprehensive report on the vegetation of an area extending as far north as Arcoona. Her studies covered the period 1927–30. However, although she recorded 387 plant species in the Lake Torrens region, including part of the Arcoona Tableland, she did not provide a species list.

Photo 1 Site 40a1

Photo 2 Site 40a13

Photo 3 Site 40a5

FIGURE D1.2
Site 40a vegetation quadrants

Photo 1 Site 45a1

Photo 2 Site 45a13

Photo 3 Site 45a7

FIGURE D1.3
Site 45a vegetation quadrants

Photo 1 Site 52a1

Photo 2 Site 52a10

Photo 3 Site 52a7

FIGURE D1.4
Site 52a vegetation quadrants

The major study of Jessup (1951) provided the first quantitative data on the vegetation of the North West Pastoral Area, including the Arcoona Tableland. He listed the plants recorded in various vegetation associations and was the first worker in this region to adopt a vegetation association based approach. Lay (1979) and Maconochie (Maconochie and Lay 1996) subsequently repeated Jessup's surveys. The methods devised by Jessup and repeated by Lay and Maconochie have formed the basis of the South Australian Government's rangeland monitoring and assessment program.

Preparation of the Environmental Impact Statement for the Olympic Dam Mine (Kinhill-Stearns Roger 1982) led to a major focus on the biological values of an area mainly to the north of the Arcoona Tableland but also including some northern parts of the tableland. As part of this work, study of the regional vegetation was carried out during the early 1980s (Fatchen 1981). However, this fieldwork was carried out during severe drought conditions and only 138 taxa were recorded from the Roxby and Arcoona land systems. The species list contained few annual or ephemeral species. A supplementary study of the vegetation of service corridors for the mine and town (Fatchen and Associates 1982) listed 79 taxa. This regional list has been increased through later work by Olympic Dam biologists to include at least 748 taxa (Olympic Dam Operations 1996) and additional species are occasionally still recorded from the area.

Later studies carried out on behalf of the Olympic Dam Operations that are relevant to the present study included a vegetation survey of a corridor from Olympic Dam to Port Augusta for a new power line. One section of this study traversed the Arcoona Tableland and quantitative data on the vegetation composition and abundance were collected using similar methods to those of the present survey (Badman 1992).

D1.2.2 The Focus of Vegetation Studies

Lange and Fatchen (1990) described the change in focus of botanical research, from a 'search for the new' approach by the explorers of the mid-19th century, often to the exclusion of the common species, to the more analytical approach that is widely used today. The early taxonomic focus had begun to change to an ecological one dealing with vegetation associations by the time of the Horn Expedition of 1894, with a more analytical focus since the late 1960s. This has led to the present management-based approach to vegetation studies, often focusing on species that have economic significance to the pastoral industry (e.g. Jessup 1951; Lay 1979; Lay et al. 1993; Maconochie and Lay 1996) or on the rare and endangered elements of the flora (e.g. Jensen and Wilson 1980; Davies 1995).

Recent advances in computer technology now allow multivariate analysis of large and complex datasets. During the last 12 years, classification (Belbin 1991) has been widely used as a tool for comparing vegetation from various areas or from different landforms. A rapid and repeatable survey method for sampling vegetation communities has been developed by biological survey teams from the SA Department for Environment and Heritage (e.g. Brandle 1998) and repeated use of these methods for different surveys now allows comparison of vegetation recorded during different surveys.

D1.2.3 Land Systems

Land systems are areas or groups of areas with recurring patterns of differing landforms, soils and vegetation (Christian and Stewart 1953). Each land system contains a combination of land units. Land systems may have additional characteristics brought about by different land units being in close proximity to each other.

Laut et al. (1977) published a general classification of the environmental associations of South Australia, while McDonald (1992) was the first to publish a detailed description of the land systems of the Kingoonya Soil Conservation District. The Kingoonya Soil Conservation Board (1996) made some changes to McDonald's descriptions and Badman (2001) carried out a major review of these land systems.

The three sites that form the present study area all fall entirely within the Arcoona land system. Badman (2001) recently reviewed this land system and his description is given below:

> The gently undulating tableland of the Arcoona land system dominates the south-east of the [Kingoonya Soil Conservation] District on Arcoona, Bosworth, Andamooka, Purple Downs, Roxby Downs, Coondambo (Parakylia South block) and Wirraminna stations. A few low hills and escarpments are included within this system. Soils include stony red duplex and stony brown clay soils of the tablelands, stony clay soils over quartzite on hills, skeletal loams on escarpments and alluvial soils along watercourses.
>
> Chenopod low shrublands dominate throughout this land system, with some trees along watercourses and tall shrublands on isolated dunes. *Atriplex vesicaria* (bladder saltbush) dominates the vegetation, with *Sclerostegia* spp. (glassworts) also common. *Sclerolaena ventricosa* (salt bindyi), *Minuria cunninghamii* (bush minuria), *Frankenia serpyllifolia* (bristly-sea heath), *Sclerolaena divaricata* (tangled bindyi), *Dissocarpus paradoxus* (ball bindyi) and *Eragrostis setifolia* (neverfail) are widespread, with *Astrebla pectinata* (barley mitchell grass), *Sporobolus actinocladus* (ray grass) and *Ixiolaena chloroleuca* and *Ixiolaena leptolepis* (plover daisies) moderately common in some areas but not common across the whole land system.
>
> Isolated dunes, often with associated calcareous rises, have sparse woodland or tall shrubland vegetation where no single species dominates. *Acacia aneura* (mulga), *Acacia ligulata* (sandhill wattle) and *Acacia tetragonophylla* (dead finish) are common in this unit. The understorey commonly includes *Aristida holathera* and *Aristida contorta (*kerosene and mulga grasses). *Maireana sedifolia (*pearl bluebush), *Maireana pyramidata* (black bluebush), *Sclerolaena tatei* (Tate's bindyi) and *Zygophyllum aurantiacum* (shrubby twinleaf) are common on calcareous rises.

Neither sandy rises nor calcareous rises with *Maireana sedifolia* and *Zygophyllum aurantiacum* occur at or near any of the three potential repository sites covered by the August 2001 survey.

D1.2.4 Functional Characteristics of Regional Vegetation

The growth of tall shrubs and trees on the Arcoona Tableland is restricted almost entirely to sandy rises and the larger watercourses. Fatchen (1981) explained this in terms of plant–water balance relationships. Specht (1972) discussed this matter in some detail. There are no aquifers within the region that can provide water for even the deepest-rooted tree species, so trees and large shrubs must rely on rainfall or water runoff for their moisture requirements.

Much of the low and erratic rainfall is lost through evaporation from the soil surface and Specht (1972) considered that rainfall sufficient to be effective in plant growth occurs on an average of no more than nine days in each year. Runoff from clay soils reduces even further the amount of water that reaches the roots of plants and this problem is further exacerbated by the presence of hardpan layers in the soil. The amount of water that actually penetrates to the potential root zone of trees and is stored in the soil is therefore too little to allow the establishment of trees on the tableland.

D1.2.5 Spread of Introduced Flora in the South Australian Arid Zone

McDouall Stuart did not record any introduced species during his crossing of Australia during 1861–62 (Mitchell 1978) and the Horn Expedition recorded only one introduced plant in 1894 (Tate 1896). Eardley (1946) listed only two naturalised taxa among about 350 species collected by the Madigan expedition while crossing the Simpson Desert in 1939 (Madigan 1946). Mitchell (1979) considered that few weeds of any significance existed in Central Australia before 1954. At least 10% of the regional flora now consists of naturalised taxa (Badman 1995a, 1999).

The localities from which introduced species were first recorded are usually located along the major access routes through an area (Badman 1995a). This is currently the case along the Stuart Highway in the Woomera region. This is due to disturbance that provides a suitable niche for their establishment, easier access for the carrier of the seeds and, in the case of sealed roads, increased water subsidies at their margins that benefits germination and establishment of introduced species on disturbed areas. These tracks also provide easy access for the botanists who recorded the introduced species.

The disproportionately high number of introduced species recorded in the Gairdner–Torrens botanical region in the last 20 years, when compared to the numbers for the Lake Eyre and North-West regions (Badman 1995a), probably reflects the lack of work done in this area after Murray in 1930 until the commencement of exploration activities associated with the Olympic Dam Mine. Although RW Jessup worked extensively in the area in the late 1940s (Jessup 1951), he apparently made few collections during this time.

Badman (1995a) found that while sandy habitats and watercourses supported the greatest number of introduced species, gibber plains had a relatively low incidence of naturalised taxa. Disturbed areas were the most prone to invasion by introduced species, and establishment and maintenance of a perennial ground cover, particularly of native grasses, prevented their large-scale establishment (Badman 1995a).

Badman (1995a) found that heavy summer rainfall at Olympic Dam in conjunction with conservative management practices could significantly decrease the incidence and cover of introduced species. Once summer growing native grasses, particularly perennial species, became established they occupied the niches that would otherwise have been available for winter growing annual introduced species and prevented these from becoming established in the following winter–spring period. These grasses could remain for several years and continue to exclude exotic species. The situation was reversed only following several dry years, which saw the elimination of the perennial grasses, followed by a wet winter which allowed establishment of annual exotics in the niches vacated by the grasses.

D1.3 Methods

D1.3.1 Field Survey

Vegetation was sampled at 13 sites at each of the three potential radioactive waste repository sites. Monitoring sites were located near the centre of the inner 500 m square, mid-way along each of the sides of the inner square and mid-way between the inner square and the outer 1500 m square, and near the four corners of the outside square both inside and outside the square (Figure D1.5). Sites were located and numbered in a consistent manner (Figure D1.6) except at Site 40a where initial confusion over the correct corners of the 1500 m square led to incorrect placement of some vegetation monitoring sites. This led to the sampling of one additional site outside the 1500 m square (40a06e).

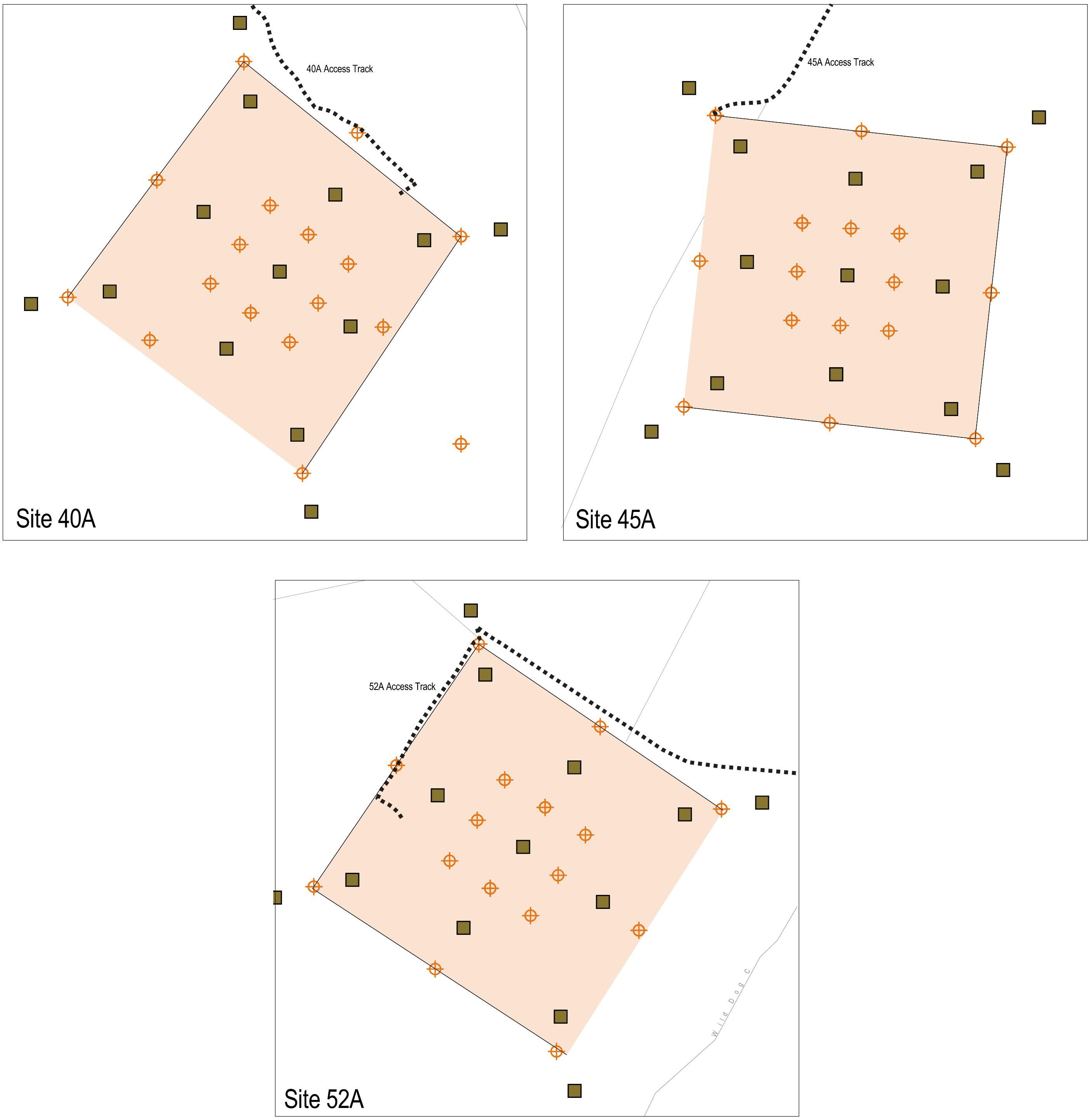
The four sites located outside the 1500 m square will allow future long-term comparisons between the vegetation inside and outside the fenced waste repository site.

Survey sites were placed in an area that was typical of the surrounding country. Very bare patches, or those that were entirely covered by vegetation that was atypical for the area, were avoided. Sites were similar in area, about 100 m in diameter, to those used for vegetation surveys by the Biological Survey and Research Section of the SA Department for Environment and Heritage (e.g. Brandle 1998), but only the Braun-Blanquet cover scores for each species (Table D1.1) and general site data were recorded. Each site was photographed and its AMG coordinates recorded (Figures D1.2, D1.3 and D1.4; Attachment A). All photographs were taken looking towards the south. No permanent markers were left at the sites but they can be relocated from the GPS coordinates. Permanent photopoint markers will be installed when the decision is made on the actual site to be used.

Voucher specimens were collected for all species that could not be positively identified in the field and these were later determined and will be lodged with the State Herbarium of South Australia.

Data collected during previous surveys of this or adjacent areas (Badman 1992, 1995a, 2001) were also used in comparisons with data collected in August 2001. These data were mainly from the Arcoona Tableland (the Painted/Breakaway land system).

In order to differentiate data from the August 2001 survey from previous data used in the PATN analysis, the letter ‘W’ is used to prefix all row labels from this survey.



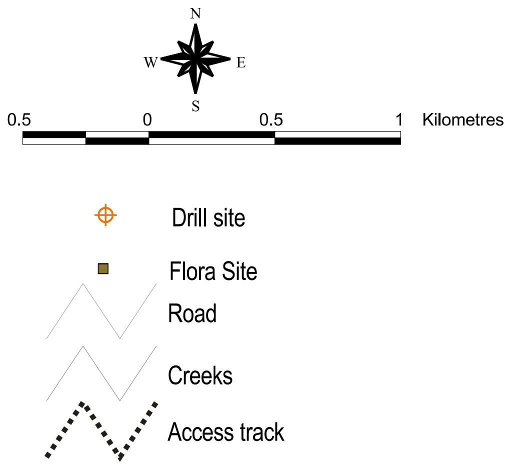


FIGURE D1.5

Flora survey locations

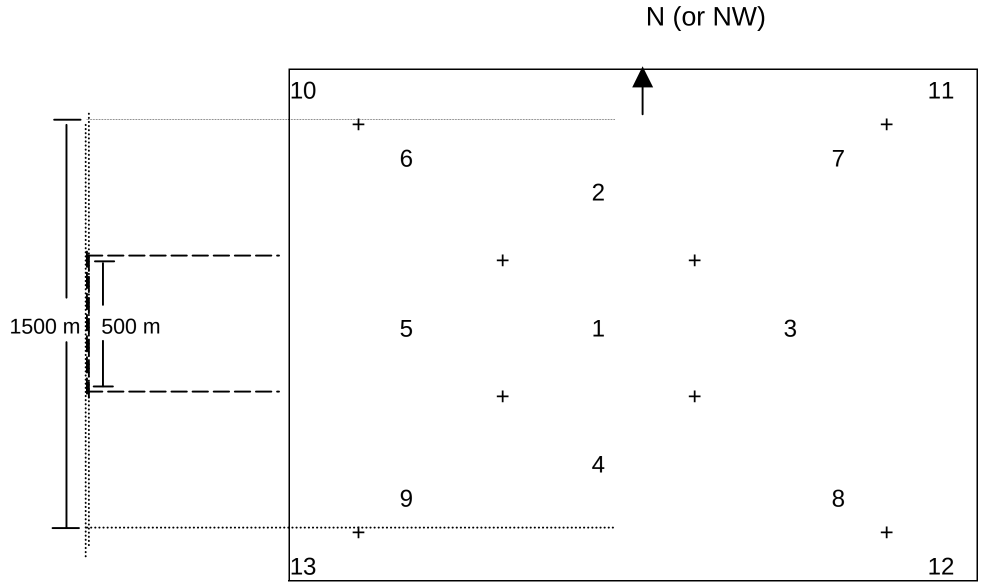


FIGURE D1.6
Layout of vegetation monitoring sites

In the interests of clarity, scientific names of plants are used throughout this report. The common names that are used in the computer program 'Florlist', which are also those now used for these species by the SA Department for Environment and Heritage's Biological Survey Branch, are given in the plant list in Attachment B.

TABLE D1.1 Modified Braun-Blanquet abundance scoring codes for cover value ranges

Score	Cover value	Score used in PATN analysis
r	Single plant	0.5
+	< 1%	1
1	1–5%	2
2	5–25%	3
3	25–50%	4
4	50–75%	–
5	75–100%	–

D1.3.2 Data Analysis

Pattern analysis (classification) was used to investigate similarities and trends in the vegetation data, both between the data collected from individual sites during the August 2001 survey and between these data and those from previous surveys. Data were classified using the PATN computer package (Belbin 1992). All species were used in the comparison of the August 2001 data, while perennial species data were used to make comparisons between different datasets. The latter is necessary because of the different seasonal conditions that prevailed at the times of different surveys. Different rainfall events, in terms of season, duration and quantity, can produce very different growth patterns among ephemeral species. In addition, most grasses grow following summer rainfall, while herbs generally grow following cool season rainfall.

The main benefit of this approach is a consistent comparison of data across the three sites, across the whole of the Arcoona Tableland and between similar adjacent land systems. Groupings are based on the cut-off point on a dendrogram. The cut-off point is adjusted to give the most appropriate number of groupings depending on which questions need to be answered.

Presence or absence of species rather than cover scores was used in comparisons of some other datasets where no cover scores could be obtained from the published reports. This was particularly the case of data from the Stony Deserts Biological Survey (Brandle 1998) where only composite data were available for vegetation groups rather than from individual sites.

For each of the various analyses, data were first entered into an Excel spreadsheet using the cover score scale shown in Table D1.1 and then converted to a format that is suitable for importation into PATN. An association matrix was created with the PATN module ASO using the Bray-Curtis coefficient of dissimilarity and then clustered with the FUSE module using flexible UPGMA (unweighted pair group arithmetic averaging). This hierarchical clustering technique provides the best fit between association measures and the distances shown on a dendrogram (Belbin 1991).

The DEND module was then used to create a dendrogram that summarises the results of the hierarchical clustering, showing the relationship of all sites to each other. The dendrogram can be cut at any level of dissimilarity to produce a number of groups. Various cut-off levels can be used until groupings reflect meaningful vegetation types based on common and repeated occurrences of particular species. The GDEF module of PATN was used to define the composition of the chosen groups and list the sites in each group. GSTA was used to list the importance of each species in each group.

All species that were recorded at less than three sites were removed from the analysis in all cases except in the analysis of the August 2001 data.

D1.4 Site Vegetation

D1.4.1 Results

Comparison of Vegetation at the Three Potential Sites

The August 2001 survey identified 126 individual plant taxa from 40 monitoring sites. These were all recorded from a single habitat on the Arcoona Tableland, the gibber plain. The other significant habitats of watercourses, lake shores and sand dunes were not sampled during this survey. This species list represents about 28% of the species recorded for the Arcoona Tableland in Attachment B.

The dendrogram obtained from a classification of the data from the August 2001 survey is shown in Figure D1.7. This indicates that the vegetation at all sites would be placed into a single floristic group at the 0.79 level of dissimilarity. Two monitoring sites at Site 52a are separated from all others at the 0.66 level of dissimilarity. To put this into perspective, Brandle (1998) used a first cut-off point of 1.06 and a maximum of 1.89 for his classification of vegetation of the stony deserts of northern South Australia, which includes the present study area. This produced 36 groups, but at the same level of dissimilarity all monitoring sites at the three potential repository sites would fall into the same group. The floristic composition of vegetation at the three potential sites is really quite similar.

Four floristic groups are identified at the 0.52 level of dissimilarity. The first group includes all but one of the sites from Site 40a; the second group includes the remaining site from Site 40a, one site from Site 45a and all but two of the sites from Site 52a; the third group includes the remaining sites from Site 45a; and the fourth group contains the remaining two sites from Site 52a. At the 0.65 level of dissimilarity, all sites except the two sites from Site 52a that form Group 4 above are included in a single group.

Differences between the four floristic groups are due to presence or absence of one or more individual species, as well as to greater or lesser cover scores for individual species. The most obvious difference is the two adjacent monitoring sites at one corner of Site 52a where the vegetation is dominated by Maireana astrotricha rather than Atriplex vesicaria. The main differences between the abundance of the most common perennial species at individual sites are shown in Table D1.2.

The presence of both *Chenopodium nitrariaceum* and *Muehlenbeckia florulenta* at monitoring site W40a05 made this site different enough to place it in the same group as the majority of Site 52a monitoring sites. Increased cover of *Abutilon halophilum* and the absence of *Eragrostis* spp., *Euphorbia stevenii, Frankenia serpyllifolia*[2]*, Maireana appressa* and *Sclerolaena brachyptera* was enough to place site W45a07 in the same group as monitoring sites at Site 52a.

Most of the common annual and ephemeral species were found at all three sites. The only species whose abundance may have influenced the floristic groupings identified in the dendrogram was Phlegmatospermum cochlearinum, which was most common at Site 40a and least common at Site 52a.

In the last column of Table D1.2, the three potential sites are compared to the findings of Badman (2001) for the Arcoona land system as a whole.

TABLE D1.2 Comparison of the abundance of the common perennial species at the three sites

Species	Site 40a	Site 45a	Site 52a	Badman (2001)
Astrebla pectinata	Not recorded	Most common	Present	Present
Atriplex vesicaria	Most common	Common	Common	Common
Dissocarpus paradoxus	Present	Present	Least common	Present
Euphorbia stevenii	Present	Present	Least common	Present
Frankenia serpyllifolia	Present	Most common	Least common	Present
Ixiolaena chloroleuca	Not recorded	Most common	Present	Present
Maireana appressa	Present	Present	Least common	Present
Maireana astrotricha	Trace	Present	Present	Present
Minuria cunninghamii	Present	Least common	Most common	Present
Sarcostemma viminale	Not recorded	Not recorded	Present	Present
Sclerolaena brachyptera	Most common	Present	Present	Present
Sclerolaena divaricata	Most common	Present	Least common	Present
Sclerolaena intricata	Present	Present	Least common	Present
Sclerostegia spp.	Most common	Present	Present	Present
Sida spp.	Not recorded	Present	Not recorded	Present

The control sites, located outside the 1500 m square, do not form floristic groups on their own, except to some extent at Site 45a, and are therefore representative of the vegetation of the site as a whole. At Site 45a, the control sites form a group with two other monitoring sites at the 0.3 level of dissimilarity. This means that they are still very similar floristically to the other Site 45a monitoring sites.

Comparison with other Regional Areas in Similar Landforms

A binary (presence or absence of species with no cover scores) classification carried out on perennial species from sites on the Arcoona Tableland produced similar results to the classification of all species discussed in the previous section. The dendrogram from this classification is shown in Attachment C.

Ten floristic groups are identified from the dendrogram in Attachment C at the 0.67 level of dissimilarity. The first six groups contain no sites from the August 2001 survey, while the seventh group contains a single site, W45a07. This is the site discussed above that differs from other monitoring sites at Site 45a by the presence of *Chenopodium nitrariaceum* and *Muehlenbeckia florulenta*. Group 8 contains the remaining monitoring sites from Site 45a. Group 9 contains all of the monitoring sites from Site 40a and

[2] All of the material collected was identified as this species using the treatment from the Flora of South Australia (Jessop and Toelken 1986). However, the majority of material from Sites 45a and 52a is identified as *Frankenia serpyllifolia* in the Flora of South Australia treatment. However, the South Australian treatment is under review and no decision has yet been made as to whether *F. planifolia* will be retained with *F. serpyllifolia* or again treated as a separate species.

six monitoring sites from Site 52a. The remaining monitoring sites from Site 52a make up the last floristic group.

The level of dissimilarity that gives these 10 groups is still quite low, meaning that the vegetation of the Arcoona Tableland is quite similar when classified on the presence or absence of perennial species. The main difference between the first six floristic groups is a paucity of records of *Sclerolaena spp*. amongst members of these groups, particularly the combination of Sclerolaena spp. that was found at most monitoring sites during the August 2001 survey. Although this genus consists of mainly perennial species, they are short-lived perennials and some or all species may have been absent during the surveys whose data were used in this analysis. None of these surveys was carried out under seasonal conditions that were as good as those occurring at the time of the August 2001 survey.

Similar comments apply to several other short-lived species or genera that are missing from sites that make up the first six groups. These include *Abutilon halophilum*, *Dissocarpus paradoxus*, *Euphorbia stevenii* and *Sida* spp. *Maireana appressa* is also missing from the datasets for all the sites in these six groups. This is a shorter-lived species than most of the other members of this genus and its numbers are known to often fluctuate in response to seasonal conditions (Badman 2000).

A cut-off point on the dendrogram in Attachment C at the 0.77 level of dissimilarity would place all of the last four floristic groups into a single group, including monitoring site W45a07, and reduce the first six groups to three groups.

Comparison with Different Regional Landforms

A comparison of the floristic data from the three potential radioactive waste repository sites with floristic data from the rest of the Kingoonya Soil Conservation District (Badman 2001) shows distinct similarities between the radioactive waste repository site data and several other sites in different land systems. The first part of the dendrogram from this classification, including all of the Arcoona Tableland sites, is shown in Attachment D.

This classification, using data from 450 sites, uses cover scores for all perennial species and, omitting annual and ephemeral species, still places most of the vegetation monitoring sites from the August 2001 survey in the same vegetation group at the 0.90 level of dissimilarity. Three monitoring sites are within another group.

The three different monitoring sites are all from Site 52a. They are the adjacent monitoring sites W52a06 and W52a10, and W52a13. These are placed in this different floristic group mainly because of their higher cover of *Maireana astrotricha.* Other differences are a greater cover of *Astrebla pectinata, Dissocarpus biflorus* and *Osteocarpum dipterocarpum* than the rest of the August 2001 survey sites, and lower cover of *Eragrostis setifolia*, *Euphorbia stevenii, Frankenia serpyllifolia, Sclerolaena divaricata* and *Sclerolaena intricata.*

Both floristic groups containing the August 2001 monitoring sites are made up almost entirely of sites from the Arcoona land system, with a few sites from the Paisley, Oodnadatta, Wattiwarriganna and Ebunbanie land systems. The Paisley and Oodnadatta land systems are both gibber plain land systems with many similarities to the Arcoona land system. The Wattiwarriganna land system is formed from a combination of dunes and broad swales. The swale vegetation is similar in composition to much of the adjacent gibber plain vegetation (Badman 2001). The Ebunbanie land system is based on granite hills and outcrops and occurs to the southwest of the Arcoona Tableland. Badman (2001) identified similarities between small areas of this land system and the Arcoona land system.

D1.4.2 Comparisons with Previous Surveys

Three main surveys are considered here, those of Jessup (1951), Brandle (1998) and Badman (2001). These workers have all described the vegetation communities of the Arcoona Tableland in some detail. A comparison of the floristic composition of the vegetation reported by these authors is given in Attachment E and a summary of the main species in Table D1.3.

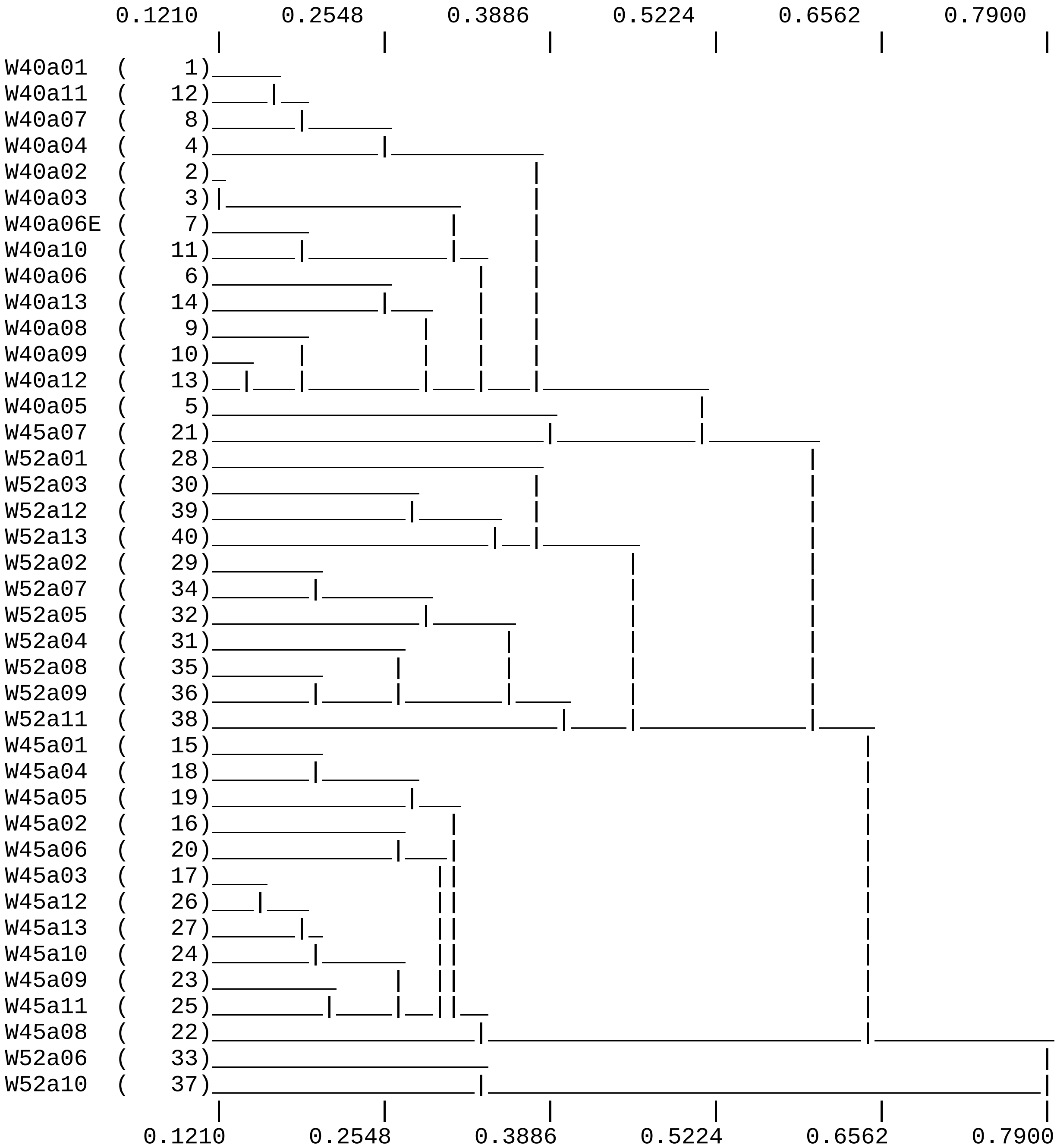


FIGURE D1.7
Floristic groups from PATN — Dendrogram of all vegetation data from the three potential sites

A complete list of species recorded during the various surveys listed below is given in Attachment E.

Jessup (1951) described two shrub–steppe vegetation associations from the Arcoona Tableland: the *Atriplex vesicaria–Ixiolaena leptolepis* association and the *Atriplex nummularia* ssp. *omissa* association. The former is the more common, while the latter is largely restricted to northern parts of the tableland. The *Atriplex vesicaria–Ixiolaena leptolepis* vegetation association was considered by Jessup to be similar to the ‘saltbush’ association previously described by Murray (1931). The list of plants reported by Jessup and given in Table D1.3 also includes several species that he recorded along watercourses and on lakeshores, rather than on the tableland itself.

TABLE D1.3 The main species from the Arcoona Tableland

Species	Jessup (1951)	Brandle (1998) Group no. 28	34	35	36	Badman (2001)	This survey Site no. 40a	45a	52a
Abutilon halophilum	FC	C		FC	FC	U	U	U	U
Astrebla pectinata	VC	C		C		FC		C	U
Atriplex vesicaria	D	C	D	D	D	D	D	D	D
Dissocarpus paradoxus	R	C		C	U	C	C	C	FC
Eragrostis australasica	FR	FC				U	FC	FC	U
Eragrostis setifolia	VC	FC	C	D	FC	C	FC	FC	FC
Euphorbia stevenii	FR	FC				U	FC	FC	U
Frankenia serpyllifolia	R	FC		C	C	C	FC	C	FC
Ixiolaena chloroleuca		FC						FC	U
Ixiolaena leptolepis	D[1]	C		U	U	FC		U	
Maireana aphylla	R	C	FC	U		U	U	C	FC
Maireana appressa	VR	+				U	FC	FC	FC
Maireana astrotricha	VR		D		U	FC	U		C
Maireana georgei	VR	+				U	U	U	U
Minuria cunninghamii		FC			C	C	FC	FC	FC
Minuria denticulata	FC	FC					R		
Minuria leptophylla	C								
Osteocarpum dipterocarpum	R	FC				U	FC	FC	FC
Panicum decompositum	VC	+							
Sclerolaena brachyptera	FC	FC	C	FC	FC	C	FC	FC	U
Sclerolaena divaricata	R			D	C	C	C	FC	U
Sclerolaena intricata				C	FC	FC	FC	FC	U
Sclerolaena ventricosa	FR	D	C	C	FC	C	C	C	C
Sclerostegia medullosa		FC	U	C	D		C		C
Sclerostegia sp.				U		C			
Sclerostegia tenuis	C				U			C	
Sida trichopoda	C	C						FC	
Sporobolus actinocladus	VC		FC	FC		FC	U	U	

D = dominant, C = common, FC = fairly common, FR = fairly rare, R = rare, VR = very rare, U = uncommon
(See Attachment E for further explanation of how ratings were allocated)
(1) *Ixiolaena leptolepis* in Jessup's list includes *Ixiolaena chloroleuca.*

Badman (1999) discussed Jessup's use of *Ixiolaena leptolepis* (which includes *Ixiolaena chloroleuca*, a species that was not described at that time). *Ixiolaena* spp., particularly *Ixiolaena chloroleuca,* are generally restricted to gilgais on the Arcoona Tableland, while the ubiquitous *Minuria cunninghamii* is far more common and would have been a more useful character species. Jessup did not include *Minuria cunninghamii* in his list, but instead had *Minuria leptophylla* as a 'Common' species. Because none of the later workers recorded *Minuria leptophylla*, it is likely that the species Jessup was referring to is really *Minuria cunninghamii.*

Jessup (1951) describes two vegetation units from the Arcoona Tableland, gilgais and the gibber-covered shelves between the gilgais. He reported that these shelves were mostly devoid of vegetation, a statement that is no longer true. Maconochie and Lay (1996) reported on the improvement of the country since the time of Jessup's surveys.

It is more difficult to make direct comparisons with Brandle (1998). Brandle's report covered almost 1100 sites from the Stony Deserts of northern South Australia. His floristic groups that occur on the Arcoona Tableland therefore also include many sites from other areas. Four of Brandle's groups are widespread on the Arcoona Tableland, although none is restricted to this area. These are group 28 (*Sclerolaena ventricosa* low open sub-shrubland), group 34 (*Maireana astrotricha–Atriplex vesicaria–Maireana pyramidata* low open shrubland), group 35 (*Sclerolaena divaricata–Eragrostis setifolia–Atriplex vesicaria* low open shrubland, and group 36 (*Atriplex vesicaria–Sclerostegia medullosa* low very open shrubland).

Components of all of these groups were found during the August 2001 survey, although, perhaps because of better seasonal conditions, none were found to form separate floristic groups. Brandle's groups 35 and 36 appear to be closest to the vegetation recorded during the August 2001 survey, an assertion supported by the dendrogram in Attachment C.

Seasonal conditions play a large part in the composition of the understorey at any given time. As an example, *Brachycome dichromosomatica* was recorded only once by Brandle (1998) and not at all by Jessup (1951) and yet this was one of the most common species at the time of the August 2001 survey. Similarly, *Phlegmatospermum cochlearinum* was not recorded by Jessup or Brandle, but was quite common in August 2001. *Erodium crinitum* was also far more common during August 2001 than was reported from any of these earlier surveys.

Jessup (1951) reported the summer-growing grasses *Astrebla pectinata* and *Eragrostis setifolia* as being more common than they are at present. This may be due to subsequent grazing pressure, but is more likely to be due to the fact that none of the latter surveys, including the August 2001 survey, followed a wet summer. Nor do later workers support the 'Fairly Rare' status of *Eragrostis australasica* reported by Jessup. This species is also mainly summer growing, but is also dependent on standing water in swamps, which usually occur following heavy summer rainfall. Two shorter-lived grasses, *Panicum decompositum* and *Sporobolus actinocladus* were also reported to be more common by Jessup than by later workers. This may be due to increased grazing pressure, although the summer rainfall factor may again be the main reason for this.

Several species listed in Table D1.3 have increased in abundance since Jessup's survey. These include Euphorbia stevenii, Frankenia serpyllifolia, Maireana aphylla, Maireana appressa, Maireana astrotricha, Osteocarpum dipterocarpum, Sclerolaena divaricata, Sclerolaena intricata and Sclerolaena ventricosa. The increased abundance of the palatable Maireana spp. would suggest a decrease in grazing pressure, while the increase of the less palatable Sclerolaena spp. would suggest the opposite.

No naturalised or invasive taxa appear in Jessup's list (Jessup 1951). It is not known whether this is because these species were not then present, or whether they were just ignored by Jessup. Badman (1995a, 1999) discussed the historical recording and reporting of naturalised species and concluded that many of the early workers simply ignored 'weeds' because they did not form part of the native vegetation. Many of the present introduced species were collected in the area prior to the 1950s (Badman 1995a, 1999).

D1.4.3 Conservation Status of Local Vegetation

There are no vegetation communities with conservation status (Davies 1982; Neagle 1995; Specht et al. 1995) at or near any of the sites examined during the August 2001 survey, nor on the Arcoona Tableland as a whole.

Conservation Status of Individual Species

One species, *Frankenia plicata,* is listed as 'Endangered' in the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. One species that has been recorded from the Arcoona Tableland is listed as 'Vulnerable' under Schedule 8 and six species are listed as 'Rare' under Schedule 9 of the *National Parks and Wildlife (Miscellaneous) Amendment Act 2000* (SA). The species listed as 'Vulnerable' is *Atriplex kochiana* and the 'Rare' species are *Brachycome eriogona*, *Embadium stagnense, Frankenia plicata, Gratwickia monochaeta, Sclerolaena holtiana* and *Zygophyllum humillimum*.

Atriplex kochiana is known to occur in the vicinity of the Andamooka Opal field on the Arcoona Tableland, and at other widely spaced localities near Oodnadatta and Mt Lyndhurst (Badman 1995b, Davies 1995). It has a national conservation rating of Poorly Known. Davies (1995) reported four populations of this plant growing within 6 km of Andamooka Opal Field. He did not find it elsewhere despite remaining in the area for several days.

This species was not found at any of the August 2001 survey sites and has never been recorded near any of these sites.

Brachycome eriogona is also listed as 'Rare' at the national level. It has been collected on Andamooka Island. Brandle (1998) recorded it at four other places on the Arcoona Tableland. This species is more common to the north in the Lake Eyre botanical region (Brandle 1998; Badman 1999). Although the habitat would appear suitable for this species at all of the potential repository sites, and it flowers during August (Cooke 1986), it was not recorded at any of the August 2001 survey sites. Brandle (1998) recorded it widely and commonly from northwest of Lake Eyre through to south of that lake. Badman (1999) reported five other collections of this species from the north of the State.

This species is conserved in the Flinders Ranges National Park (Briggs and Leigh 1995).

Embadium stagnense is listed as 'Rare' at the national level. It is known from a collection made near Arcoona (Toelken 1986), but has not been recorded in recent times despite several searches during the late 1980s and early 1990s. It was not found at any of the August 2001 survey sites and has never been recorded near any of these sites.

Although *Frankenia plicata* is listed as 'Endangered' at the national level, Brandle (1998) recorded it at 26 sites during the Stony Deserts Survey, including eight sites on the Arcoona Tableland. He found it in a wide variety of habitats, including those present at the potential radioactive waste repository sites. Badman (2001) found this species to be fairly common in the Breakaway land system to the northwest of the present study area. It was not recorded at any of the monitoring sites during the August 2001 survey.

Gratwickia monochaeta is listed as 'Rare' at the national level. Brandle (1998) recorded it at two sites on the Arcoona Tableland, both in *Acacia ligulata* tall open shrubland on an isolated area of sand surrounded by gibber tableland. This sandy habitat does not occur at any of the potential repository sites, so the chances of this species being disturbed by the development are very remote.

Sclerolaena holtiana has a national conservation rating of 'Poorly Known'. It is known from numerous collections and records from the Arcoona Tableland (Brandle 1998; Badman 1999). It was not found at any of the August 2001 survey sites.

Badman (1999) reported that an inspection of collections in the State Herbarium of South Australia revealed seven collections from the Gairdner–Torrens botanical region and a further 68 collections from the Lake Eyre botanical region. Many of these herbarium collections were made during the Stony Deserts Biological Survey (Brandle 1998) which reported this species from 38 sites, although none of these was on the Arcoona Tableland. Badman (1999) reported several other collections from the north of South Australia and considered that the present conservation status of this plant is unwarranted.

Zygophyllum humillimum has a national conservation rating of 'Poorly Known'. Brandle (1998) recorded it at only three sites on the Arcoona Tableland, but at 25 sites during the Stony Deserts Survey. He recorded it in Floristic Group 28 on the Arcoona Tableland. It was not recorded at any of the monitoring sites during the August 2001 survey. Brandle's group 36 is considered here to be the closest to the vegetation at the three potential repository sites and therefore the chances of disturbing this species are considered to be small.

D1.4.4 Non-vascular Plants

Non-vascular plants occur throughout the arid region of Australia. Where they occur on soil surfaces they may form soil crusts which assist in the stabilisation of the soil surface (Eldridge and Tozer 1997). Soil crusts provide similar functions as groundstorey vegetation do in higher rainfall regions. They provide a protective veneer over the soil surface, reducing the potential for wind and water erosion.

Fire, grazing by sheep and cattle, and vehicle traffic are the main disturbing factors causing the breakdown of the soil crust flora in the region. Within the region, lichens are more numerous than most other non-vascular plants. (Blue-green algae were not assessed.) Table D1.4 provides a summary of the distribution of non-vascular plants recorded during the EIS field assessment.

The data provided in Table D1.4 indicate that the non-vascular plant flora of Site 45a is typical of a site that has been more heavily disturbed and has a less intact soil surface than either of the other sites.

TABLE D1.4 Non-vascular plants recorded in the project area

Non-vascular plant	Site 40a	Site 45a	Site 52a
Lichens			
Acarospora sp.	✓	✓	✓
Acarospora citrina (Taylor) Zahlbr. ex Rech.	✓	✓	✓
Buellia sp.	✓		✓
Caloplaca sp.	✓	✓	✓
Collema sp.	✓	✓	✓
Endocarpum simplicatum (Nyl.) Nyl.	✓	✓	✓
Endocarpon sp. (sterile)	✓		✓
Endocarpon sp. 1	✓		✓
Endocarpon sp. 2	✓		
Lecidea sp.	✓		✓
Neofuscelia sp. 1			✓
Neofuscelia sp. 2 (isidiose)	✓		✓
Psora decipiens (Hedw.) Hoffin.	✓	✓	✓
Psora sp. (sterile)	✓		✓
Xanthoparmelia ?remanens (Elix) Elix & J. Johnst.	✓	✓	✓
Xanthoparmelia sp.			✓
Xanthoparmelia sp. 1	✓		✓
Xanthoparmelia sp. 2	✓	✓	✓
Xanthoparmelia ?sp. 3			✓
Liverworts			
Riccia crystallina L.	✓	✓	✓
Riccia limbata Bisch.(1)			✓*
Mosses			
Desmatodon convolutus (Brid.) Grout	✓	✓	✓
Didymodon torquatus (Taylor) Catches.(1)			✓*
?*Pterygoneurum* sp.	✓		✓
Total taxa	19	10	23

(1) Recorded from gully adjacent to Lake Koolymilka

A number of lichens are sensitive to environmental change (Eldridge and Tozer 1997), and consequently may be valuable indicators for monitoring and assessing the construction and operational aspects of the repository facilities.

None of the species recorded is of listed or known conservation significance (G. Bell, Plant Biodiversity Centre, State Herbarium, pers. comm., December 2001).

Lichens

Lichens occurred at all sites and rock-dwelling lichens (saxicolous) were common to abundant. Lichens present on the living and dead wood of shrubs (corticolous) and on the soil surface (terricolous) were rare and less common respectively.

Analysis of the data indicates seven terricolous and 12 saxicolous lichens present in the project area. Table D1.5 provides a summary of the substrate distribution. Attachment F details the distribution of soil and rock species.

TABLE D1.5 Distribution of saxicolous and terricolous lichens

Lichen	Site 40a	Site 45a	Site 52a
Saxicolous	8	3	13
Terricolous	6	5	6
Total	14	8	19

Past land management practices, such as high stocking rates, have probably influenced the abundance of terricolous lichens. While Site 45a has a similar diversity of soil lichens (five species) to the other sites, all soil-dwelling lichens at Site 45a are very sparsely distributed.

Liverworts

One species of liverwort, *Riccia crystallina*, was present at all sites but was confined to locations in and along the edge of drying canegrass swamps. *Riccia limbata* was collected in the region, but was not observed at any of the sites.

Mosses

Mosses are generally indicators of soils receiving higher moisture, either through rainfall or surface runoff. Consequently, many of the specimens recorded on the Arcoona Tableland are located in depressions and/or canegrass swamps. The moss *Desmatodon convolutus* was recorded at all three sites. *Pterygoneurum sp*. was also recorded at Sites 40a and 52a. *Didymodon torquatus*, although not recorded at any site, is present in the region.

D1.4.5 Access Roads

No quantitative vegetation studies were carried out along access roads to any of the potential repository sites. The various access options for each of the sites were inspected and qualitative assessments were made of the vegetation that would be affected by each option. These options do not take into account any Native Title or Aboriginal heritage implications for that particular route. Heritage surveys would be required to decide on potential access before any useful quantitative assessment of the vegetation could be made.

Two land systems are traversed by the access road options described below. These are the Arcoona land system described above and the Roxby land system. Badman (2001) described the Roxby land system, which occurs to the north and west of the Arcoona Tableland on Roxby Downs, Parakylia, Billa Kalina, Andamooka, Purple Downs, Arcoona and Wirraminna stations, as:

> …a large dunefield overlying older alluvial plains or ancient basement limestone. Limestone is often very close to the surface or occurs as outcrops. Red duplex soils or firm calcareous sands overlie the limestone, while siliceous sands occur on dunes and firm calcareous sands occur on rises. Alluvial silts and clays are associated with drainage channels, claypans and swamps.
>
> Mulga [*Acacia aneura*] woodlands are dominant in the main vegetation association, with white cypress-pines [*Callitris glaucophylla*] also common on the larger dunes and horse mulga [*Acacia ramulosa*] common on siliceous sands of both large and small dunes. Tall shrublands of sandhill wattle [*Acacia ligulata*], narrow-

leaved hopbush [*Dodonaea viscosa* ssp. *angustissima*] and bullock bush [*Alectryon oleifolius*] are also common on dunes. Understorey is often dominated by kerosene grass [*Aristida holathera*], with sand sida [*Sida ammophila*], ruby saltbush [*Enchylaena tomentosa*] and rosy bluebush [*Maireana erioclada*] all widespread but not common throughout the whole unit. Western myall [*Acacia papyrocarpa*] and mulga woodlands are common in swales and white cypress-pine occurs in some swales with deep sandy soils. Tall shrubland of senna [*Senna artemisioides* subspp.] are widespread and low shrublands of bladder saltbush [*Atriplex vesicaria*] and low bluebush [*Maireana astrotricha*] are common in the understorey of swales, although these are usually dominated by mulga grass [*Aristida contorta*]. Australian boxthorn [*Lycium australe*], ball bindyi [*Dissocarpus paradoxus*], oblique-spined bindyi [*Sclerolaena obliquicuspis*] and desert lantern bush [*Abutilon otocarpum*] are widespread but not common throughout the whole association.

The other floristic groups represent changes in abundance of particular species rather than distinct land units. Small swamps are often bordered by *Melaleuca xerophila* (tea tree low woodlands). *Eragrostis australasica* (swamp canegrass) is also common in or bordering such places. These areas are usually quite small. Claypans are more common than swamps, but very little vegetation grows on them. They are often bordered by halophytic species, particularly chenopods, but these areas usually support the same species as the surrounding swales.

Site 40a

The track used for access to this site (Figure 7.2) is nearly twice as long as the straight-line distance between the site and Woomera. It traverses the undulating gibber plains of the Arcoona Tableland (Arcoona land system), a number of tableland escarpments and would also have to cross one large watercourse and several minor ones. Watercourse crossings are sandy.

This route does not encounter any vegetation that is significantly different from that recorded at other monitoring sites on the tableland.

Site 45a

The current access is from the Pimba to Olympic Dam road along the Andamooka Homestead access road and then the old Arcoona to Andamooka Opal Field access road (Figure 7.2). It crosses areas of both the Roxby and Arcoona land systems.

Providing that all road material was obtained from the existing, defined road area only, upgrading the track could be practicable.

Site 52a

The access to this site follows existing major roads (Figure 7.2) through the Woomera Prohibited Area (WPA) (Arcoona land system). The majority of these roads have a bitumen surface and there would be no effect on native vegetation other than that which already occurs during routine road maintenance activities.

D1.4.6 Introduced Plants

Ten of the 126 species (8%) recorded during the August 2001 survey are introduced taxa. This figure is lower than the overall percentage of introduced taxa that have been recorded on the Arcoona Tableland. Attachment B lists 453 taxa, of which 57 (13%) are introduced. Badman (1999) considered that naturalised species made up about 10% of the total flora of northern South Australia (excluding the Flinders Ranges). Badman (1999) also gave 13% as the figure for the Olympic Dam region, just to the north of the present study area, which includes a greater diversity of habitats.

The low incidence of introduced taxa recorded during the August 2001 survey may be partly due to the relatively undisturbed condition of the study sites. None of these sites is completely undisturbed and Laut et al. (1977) described this area as being in a 'disturbed natural' condition. The whole region has a long history of grazing by native, domestic and feral herbivores, as well as being subject to the operations of sheep and cattle stations. In addition, Site 52a has been heavily disturbed by the operations in WPA, as shown by the large amount of old infrastructure scattered across the site. Despite this, the sites remain relatively undisturbed by ground disturbing activities other than the feet of animals.

D1.4.7 Management Considerations

Impacts and risks can be managed and in most cases minimised by careful planning before any ground-disturbing work is begun. Likely and possible impacts and risks during construction, operation and decommissioning are shown in Table D1.6.

TABLE D1.6 Likely and potential impacts during construction, operation and decommissioning

Potential impact	Construction	Operation	Decommissioning
Disturbance to vegetation	H	L	L
Loss of topsoil	H	L	M
Interception and concentration of surface water flows	M	L	L
Altered drainage patterns to swamps and drainage channels	M	L	L
Accelerated erosion from excavations in drainage channels	L	L	L
Erosion of dispersive soils	M	L	M
Rutting of surface by construction traffic	M	L	M
Dust from trafficked areas	M	L	M
Introduction of weeds	M	M	M
Fire	L	L	L

H = high risk, M = medium risk, L = low risk (risks are assessed on the assumption that guidelines given below will be followed)

D1.4.8 Vegetation Clearance

Initial site clearance should involve only the vegetation that must be removed to carry out construction activities. Vegetation must not be removed on the assumption that the area may need to be cleared at some stage in the future, possibly for future extensions to the repository area. Maintaining native vegetation will minimise dust and erosion problems, as well as the introduction of weeds. Once the repository is established, all future activities should be kept to existing roads, tracks and hardstand areas.

Topsoil Management

Any topsoil that is removed during construction must be stockpiled for future use. Cleared vegetation could be stockpiled separately, but if the life of the repository is long, they could be placed on top of the topsoil stockpile. This would provide additional protection of the topsoil from wind and water erosion and also provide a vegetated stockpile that would be an ongoing seed bank. Topsoil stockpiles should be placed on flat ground wherever possible and if necessary protected from water erosion by the construction of suitable banks and drains.

Erosion

The potential for erosion of soils on gibber tablelands is greatest when the protective gibber mantle is removed or disturbed. This is most likely to occur during construction. Any gibbers that are removed from the central repository area must be stockpiled separately from topsoil and other material so that they can be replaced as part of decommissioning. Care must be taken not to alter flows in any drainage channel, either by blocking it off or by excavating across or within the channel. This is likely to be a greater problem at Site 40a than at other sites.

Introduction of Weeds and Plant Pathogens

It is generally recognised that any form of ground disturbance provides an opportunity for the establishment of weed species. However, this can be minimised by good management practices. These can include:

- minimising the area that is disturbed
- preventing the introduction of seeds, particularly of species that are not already present in the area by:
  - thoroughly cleaning any plant, machinery or vehicles that are brought on to site during construction
  - ensuring that trucks carrying waste material to the repository do not introduce seeds into the area (this may also entail thorough cleaning of trucks that have come from infected areas)
- promoting the establishment of perennial native grasses
- prompt removal of any weeds, particularly perennial species, before they become established.

Increasing the number of vehicles potentially from different areas of Australia would increase the risk of introducing new plant pathogens.

Fencing

In order to exclude large fauna from the site, a fence of equal construction to the dog fence will be required. Normal station type cattle and sheep fences will not exclude kangaroos, which are able to jump over a fence of this height. Rabbit netting will be required to exclude rabbits. The outer fencing should be of such a standard that the area becomes a wildlife refuge similar to, but much smaller than, the Arid Zone Recovery Project at Olympic Dam.

The area cleared for fence construction should be the minimum necessary for safe construction and maintenance of the fence. This should be no more than a grader blade width on either side.

Fire Management

Fire is generally not a serious problem on the chenopod shrublands of the Arcoona Tableland. However, fire may occur in this habitat following exceptional seasons if a substantial fuel load of mainly grasses has built up in the understorey (Kingoonya Soil Conservation Board 1996). A cleared track two grader blades wide around both fences will provide adequate protection from bushfires. Under extreme conditions, these cleared areas could be used as a base for back-burning operations to protect the repository area.

Decommissioning

The recommended end-use of the repository site is as a biological reference area for the Arcoona Tableland. The minimal approach to vegetation removal and impacts suggested above would also assist in achieving this goal. Depending on the amount of monitoring required for the repository site itself, most hardstand areas might be suitable for rehabilitation. This would require standard rehabilitation techniques including the removal of hardstand, particularly where it contained light-coloured material such as limestone, ripping and seeding with locally collected seed.

D1.4.9 Monitoring

The vegetation monitoring was carried out in such a way that four of the monitoring sites at each or the three potential waste repository sites will be outside the outer fence when this is constructed. These monitoring sites can act as control sites to detect any changes in vegetation that may occur inside the fenced area as a result of the storage of the waste material.

The central vegetation monitoring site at each of the potential storage sites will be destroyed during construction of the storage facility. There will still be eight sites inside the perimeter fence, including four sites midway between the inner and outer fences and four sites near the outer corners, which can be used for ongoing vegetation monitoring.

Because of the rapid assessment methods used in the survey, there will be little advantage in carrying out annual or more frequent monitoring beyond the first few years after the repository is established unless there are obvious changes to vegetation inside the fenced area. Monitoring is envisaged after the first few years at temporal intervals in the order of five years. Vegetation monitoring should be staged so as to take advantage of good seasons, especially following summer rainfall. This will allow the compilation of a more complete database on the local vegetation, including the summer-growing grasses that were absent at the time of the August 2001 survey.

Subtle changes in the vegetation that cover a large area would not be detected by these methods, but changes can be identified by comparisons with the baseline data for perennial species at each monitoring site. If such changes are suspected and the control sites outside the fence are in similar condition also and thought to be affected, this can be checked by comparisons with the vegetation of several new sites further away from the repository site.

The repository site could form an important reference area for vegetation monitoring programs on the Arcoona Tableland. It could have importance for Commonwealth and State Government and for local communities. These could include the Council for Sustainable Vegetation Management, Department of Defence, South Australian Rangelands Program and local soil conservation boards.

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D1.6 Attachment A: Coordinates of Monitoring Sites

Site number	Easting	Northing	Photo bearing
W40a01	695225	6545591	190
W40a02	695424	6545917	190
W40a03	695456	6545433	188
W40a04	694785	6545334	120
W40a05	694817	6545866	200
W40a06	694861	6546596	150
W40a07	695960	6545791	184
W40a08	695230	6544746	182
W40a09	694237	6545501	170
W40a10	695003	6546819	157
W40a11	696222	6545836	166
W40a12	695198	6544477	177
W40a13	693817	6545497	146
W45a01	705795	6587176	148
W45a02	705658	6587675	130
W45a03	706015	6587159	157
W45a04	705571	6586805	185
W45a05	705277	6587357	187
W45a06	705007	6587897	193
W45a07	706317	6587698	202
W45a08	706226	6586492	183
W45a09	704904	6586706	147
W45a10	704825	6588047	176
W45a11	706579	6587952	186
W45a12	706389	6586572	190
W45a13	704378	6586670	185
W52a01	636924	6573648	213
W52a02	637056	6573949	203
W52a03	637179	6573453	184
W52a04	636549	6573331	180
W52a05	636544	6573887	149
W52a06	636659	6574580	158
W52a07	637703	6573834	183
W52a08	636961	637035	152
W52a09	636018	6573475	188
W52a10	636734	6574679	187
W52a11	637992	6573889	163
W52a12	637035	6572498	174
W52a13	635894	6573455	187

D1.7 Attachment B: Plant Species List for the Arcoona Tableland

Species by family in Engler order		AUS[1]	SA[2]
Adiantaceae			
Cheilanthes lasiophylla	woolly cloak-fern		
Marsileaceae			
Marsilea costulifera	narrow-leaf nardoo		
Marsilea drummondii	common nardoo		
Marsilea exarata	swayback nardoo		
Marsilea hirsuta	short-fruit nardoo		
Casuarinaceae			
Casuarina pauper	black oak		
Urticaceae			
Parietaria cardiostegia	mallee smooth-nettle		
Proteaceae			
Hakea leucoptera ssp. *leucoptera*	silver needlewood		
Santalaceae			
Exocarpos aphyllus	leafless cherry		
Santalum lanceolatum	plumbush		
Loranthaceae			
Amyema maidenii ssp. *maidenii*	pale-leaf mistletoe		
Amyema miquelii	box mistletoe		
Amyema miraculosum ssp. *boormanii*	fleshy mistletoe		
Amyema preissii	wire-leaf mistletoe		
Amyema quandang var. *quandang*	grey mistletoe		
Lysiana exocarpi ssp. *exocarpi*	harlequin mistletoe		
Polygonaceae			
**Acetosa vesicaria*	rosy dock		
**Emex australis*	three-corner jack		
Muehlenbeckia florulenta	lignum		
Polygonum plebeium	small knotweed		
**Rumex crispus*	curled dock		
Rumex crystallinus	glistening dock		
Nyctaginaceae			
Boerhavia coccinea	tar-vine		
Boerhavia dominii	tar-vine		
Boerhavia schomburgkiana	Schomburgk's tar-vine		
Aizoaceae			
Disphyma crassifolium ssp. *clavellatum*	round-leaf pigface		
Glinus lotoides	hairy carpet-weed		
Gunniopsis calva			
Gunniopsis papillata	twin-leaf pigface		
Gunniopsis quadrifida	Sturt's pigface		
Gunniopsis septifraga	green pigface		
**Mesembryanthemum nodiflorum*	slender iceplant		
Sarcozona praecox	sarcozona		
Tetragonia eremaea	desert spinach		
Tetragonia tetragonioides	New Zealand spinach		

Species by family in Engler order		AUS(1)	SA(2)
Trianthema triquetra	red spinach		
Zaleya galericulata	hogweed		
Portulacaceae			
Anacampseros australiana	Australian anacampseros		
Calandrinia eremaea	dryland purslane		
Calandrinia polyandra var. *polyandra*	parakeelya		
Calandrinia remota	round-leaf parakeelya		
Calandrinia volubilis	twining purslane		
Portulaca oleracea	common purslane		
Caryophyllaceae			
**Gypsophila tubulosa*	annual chalkwort		
**Herniaria cinerea*	rupturewort		
**Spergularia diandra*	lesser sand-spurrey		
**Spergularia marina*	salt sand-spurrey		
Chenopodiaceae			
Atriplex angulata	fan saltbush		
Atriplex crassipes var. *crassipes*			
Atriplex eardleyae	Eardley's saltbush		
Atriplex fissivalvis	gibber saltbush		
Atriplex holocarpa	pop saltbush		
Atriplex kochiana	Koch's saltbush	(3K)	V
Atriplex leptocarpa	slender-fruit saltbush		
Atriplex limbata	spreading saltbush		
Atriplex lindleyi ssp. *conduplicata*	baldoo		
Atriplex lindleyi ssp. *lindleyi*	baldoo		
Atriplex nummularia ssp. *omissa*	old-man saltbush		
Atriplex spongiosa	pop saltbush		
Atriplex stipitata	bitter saltbush		
Atriplex velutinella	sandhill saltbush		
Atriplex vesicaria	bladder saltbush		
Chenopodium auricomum	golden goosefoot		
Chenopodium desertorum	desert goosefoot		
Chenopodium melanocarpum	black-fruit goosefoot		
Chenopodium nitrariaceum	nitre goosefoot		
Chenopodium pumilio	clammy goosefoot		
Dissocarpus biflorus var. *biflorus*	two-horn saltbush		
Dissocarpus biflorus var. *villosus*	woolly two-horn saltbush		
Dissocarpus paradoxus	ball bindyi		
Einadia nutans ssp. *eremaea*	dryland climbing saltbush		
Enchylaena tomentosa var. *tomentosa*	ruby saltbush		
Eriochiton sclerolaenoides	woolly-fruit bluebush		
Halosarcia halocnemoides	grey samphire		
Halosarcia indica ssp. *leiostachya*	brown-head samphire		
Halosarcia pergranulata ssp. *divaricata*	black-seed samphire		
Maireana aphylla	cotton-bush		
Maireana appressa	pale-fruit bluebush		
Maireana astrotricha	low bluebush		
Maireana cannonii	Cannon's bluebush		
Maireana ciliata	hairy fissure-plant		
Maireana coronata	crown fissure-plant		
Maireana eriantha	woolly bluebush		

Species by family in Engler order		AUS[1]	SA[2]
Maireana georgei	satiny bluebush		
Maireana integra	entire-wing bluebush		
Maireana microcarpa	swamp bluebush		
Maireana oppositifolia	salt bluebush		
Maireana pentatropis	erect mallee bluebush		
Maireana planifolia	flat-leaf bluebush		
Maireana pyramidata	black bluebush		
Maireana sedifolia	bluebush		
Maireana spongiocarpa	spongy-fruit bluebush		
Maireana trichoptera	hairy-fruit bluebush		
Malacocera albolanata	woolly soft-horns		
Malacocera tricornis	goat-head soft-horns		
Neobassia proceriflora	desert glasswort		
Osteocarpum acropterum var. *acropterum*	tuberculate bonefruit		
Osteocarpum dipterocarpum	two-wing bonefruit		
Rhagodia spinescens	spiny saltbush		
Salsola kali	buckbush		
Sclerolaena brachyptera	short-wing bindyi		
Sclerolaena constricta			
Sclerolaena cuneata	tangled bindyi		
Sclerolaena decurrens	green bindyi		
Sclerolaena diacantha	grey bindyi		
Sclerolaena divaricata	tangled bindyi		
Sclerolaena holtiana	Holt's bindyi	(3K)	R
Sclerolaena intricata	tangled bindyi		
Sclerolaena lanicuspis	spinach bindyi		
Sclerolaena obliquicuspis	oblique-spined bindyi		
Sclerolaena parallelicuspis	western bindyi		
Sclerolaena patenticuspis	spear-fruit bindyi		
Sclerolaena tatei	Tate's bindyi		
Sclerolaena uniflora	small-spine bindyi		
Sclerolaena ventricosa	salt bindyi		
Sclerostegia medullosa			
Sclerostegia tenuis	slender samphire		
Amaranthaceae			
Alternanthera angustifolia	narrow-leaf joyweed		
Alternanthera denticulata	lesser joyweed		
Alternanthera nodiflora	common joyweed		
Amaranthus grandiflorus	large-flower amaranth		
Amaranthus macrocarpus	large-fruit amaranth		
Amaranthus mitchellii	Boggabri weed		
Ptilotus exaltatus var. *exaltatus*	pink mulla mulla		
Ptilotus nobilis var. *nobilis*	yellow-tails		
Ptilotus obovatus var. *obovatus*	silver mulla mulla		
Ptilotus parvifolius	small-leaf mulla mulla		
Ptilotus sessilifolius var. *sessilifolius*	crimson-tails		
Cactaceae			
**Opuntia stricta* var. *stricta*	erect prickly pear		
Ranunculaceae			
Myosurus minimus var. *australis*	mousetail		
Ranunculus pentandrus var. *platycarpus*	smooth buttercup		

Species by family in Engler order		AUS(1)	SA(2)
Cruciferae			
**Alyssum linifolium*	flax-leaf alyssum		
Arabidella nasturtium	yellow cress		
Arabidella trisecta	shrubby cress		
Blennodia canescens	native stock		
**Brassica tournefortii*	wild turnip		
**Carrichtera annua*	Ward's weed		
Harmsiodoxa puberula	scented cress		
Lepidium oxytrichum	green peppercress		
Lepidium papillosum	warty peppercress		
Lepidium phlebopetalum	veined peppercress		
Lepidium rotundum	veined peppercress		
Lepidium sagittulatum	fine-leaf peppercress		
Menkea crassa	fat spectacles		
Phlegmatospermum cochlearinum	downy cress		
**Sisymbrium erysimoides*	smooth mustard		
**Sisymbrium irio*	London mustard		
**Sisymbrium orientale*	Indian hedge mustard		
Stenopetalum lineare	narrow thread-petal		
Crassulaceae			
Crassula colorata var. *colorata*	dense crassula		
Crassula sieberiana ssp. *tetramera*	Australian stonecrop		
Pittosporaceae			
Pittosporum phylliraeoides var. *microcarpa*	native apricot		
Leguminosae			
Acacia aff. *papyrocarpa*	myall		
Acacia aneura var. *aneura*	mulga		
Acacia ligulata	umbrella bush		
Acacia oswaldii	umbrella wattle		
Acacia papyrocarpa	western myall		
Acacia tetragonophylla	dead finish		
Acacia victoriae ssp. *victoriae*	elegant wattle		
Crotalaria eremaea ssp. *strehlowii*	smooth loose-flowered rattle-pod		
Crotalaria novae-hollandiae ssp. *lasiophylla*	woolly rattle-pod		
Cullen australasicum	tall scurf-pea		
Cullen cinereum	annual scurf-pea		
Cullen graveolens	native lucerne		
Cullen pallidum	white scurf-pea		
Cullen patens	spreading scurf-pea		
Glycine canescens	silky glycine		
Indigofera psammophila	sand indigo		
Lotus cruentus	red-flower lotus		
**Medicago polymorpha* var. *polymorpha*	burr-medic		
**Prosopis juliflora*	mesquite		
Senna artemisioides nothossp. *coriacea*	broad-leaf desert senna		
Senna artemisioides ssp. *filifolia*	fine-leaf desert senna		
Senna artemisioides ssp. *helmsii*	blunt-leaf senna		
Senna artemisioides ssp. *petiolaris*	flat-stalk senna		
Senna artemisioides ssp. *quadrifolia*	four-leaf desert senna		

Species by family in Engler order		**AUS(1)**	**SA(2)**
Senna glutinosa ssp. *pruinosa*	white senna		
Swainsona adenophylla	violet swainson-pea		
Swainsona phacoides	dwarf swainson-pea		
Swainsona stipularis	orange swainson-pea		
Tephrosia sphaerospora	mulga trefoil		
Trifolium tomentosum	woolly clover		
Trigonella suavissima	sweet fenugreek		
**Vicia monantha*	spurred vetch		
Oxalidaceae			
Oxalis perennans	native sorrel		
Geraniaceae			
Erodium angustilobum			
**Erodium aureum*			
**Erodium cicutarium*	cut-leaf heron's-bill		
Erodium crinitum	blue heron's-bill		
Erodium cygnorum ssp. *glandulosum*	clammy heron's-bill		
Zygophyllaceae			
**Tribulus terrestris*	caltrop		
Zygophyllum aurantiacum			
Zygophyllum compressum	rabbit-ears twinleaf		
Zygophyllum confluens	forked twinleaf		
Zygophyllum crenatum	notched twinleaf		
Zygophyllum emarginatum	notched twinleaf		
Zygophyllum eremaeum	pale-flower twinleaf		
Zygophyllum howittii	clasping twinleaf		
Zygophyllum humillimum	small-fruit twinleaf	(dKC-)	R
Zygophyllum iodocarpum	violet twinleaf		
Zygophyllum ovatum	dwarf twinleaf		
Zygophyllum prismatothecum	square-fruit twinleaf		
Zygophyllum simile	white twinleaf		
Euphorbiaceae			
Euphorbia 'Marree'(FJ Badman 776)			
Euphorbia australis	hairy caustic weed		
Euphorbia drummondii	caustic weed		
Euphorbia parvicaruncula	rough-seeded spurge		
Euphorbia stevenii	bottletree spurge		
Euphorbia tannensis ssp. *eremophila*	desert spurge		
Phyllanthus fuernrohrii	sand spurge		
Phyllanthus lacunarius	lagoon spurge		
Sauropus trachyspermus	rough-seed spurge		
Sapindaceae			
Alectryon oleifolius ssp. *canescens*	bullock bush		
Dodonaea lobulata	lobed-leaf hop-bush		
Dodonaea microzyga var. *microzyga*	brilliant hop-bush		
Dodonaea viscosa ssp. *angustissima*	narrow-leaf hop-bush		
Stackhousiaceae			
Stackhousia clementii	limestone candles		
Stackhousia muricata ssp. 'perennial' (WR Barker 3641)	yellow candles		
Malvaceae			
Abutilon cryptopetalum	hill lantern-bush		
Abutilon fraseri			

Species by family in Engler order		AUS(1)	SA(2)
Abutilon halophilum	plains lantern-bush		
Abutilon leucopetalum	desert lantern-bush		
Abutilon otocarpum	desert lantern-bush		
Abutilon oxycarpum var. *oxycarpum*	straggly lantern-bush		
Hibiscus brachysiphonius	low hibiscus		
Lavatera plebeia	Australian hollyhock		
Lawrencia glomerata	clustered lawrencia		
Malvastrum americanum	malvastrum		
Sida fibulifera	pin sida		
Sida petrophila	rock sida		
Sida trichopoda	high sida		
Frankeniaceae			
Frankenia plicata	sea heath	E	R
Frankenia serpyllifolia	thyme sea-heath		
Cucurbitaceae			
**Cucumis myriocarpus*	paddy melon		
Mukia micrantha	desert cucumber		
Lythraceae			
Lythrum hyssopifolia	lesser loosestrife		
Myrtaceae			
Eucalyptus camaldulensis var. *obtusa*	northern river red gum		
Melaleuca pauperiflora ssp. *mutica*	boree		
Melaleuca xerophila	boree		
Haloragaceae			
Haloragis sp.	raspwort		
Myriophyllum verrucosum	red milfoil		
Umbelliferae			
Daucus glochidiatus	native carrot		
Primulaceae			
**Anagallis arvensis*	pimpernel		
Limoniaceae			
**Limonium lobatum*	winged sea-lavender		
Gentianaceae			
**Centaurium spicatum*	spike centaury		
Asclepiadaceae			
Rhyncharrhena linearis	climbing purple-star		
Sarcostemma viminale ssp. *australe*	caustic bush		
Rubiaceae			
Asperula gemella	twin-leaf bedstraw		
Synaptantha tillaeacea			
Convolvulaceae			
Convolvulus erubescens	Australian bindweed		
Convolvulus remotus	grassy bindweed		
Cressa cretica	rosinweed		
Boraginaceae			
**Echium plantagineum*	salvation Jane		
Embadium stagnense	Arcoona slipper-plant	(2K)	R
**Heliotropium amplexicaule*	blue heliotrope		
**Heliotropium curassavicum*	smooth heliotrope		
**Heliotropium supinum*	creeping heliotrope		
Omphalolappula concava	burr stickseed		

Species by family in Engler order		AUS(1)	SA(2)
Plagiobothrys plurisepaleus	white rochelia		
Trichodesma zeylanicum	camel bush		
Verbenaceae			
**Verbena officinalis*	common verbena		
**Verbena supina*	trailing verbena		
Labiatae			
**Marrubium vulgare*	horehound		
Mentha australis	river mint		
Teucrium racemosum	grey germander		
Solanaceae			
Duboisia hopwoodii	pituri		
Lycium australe	Australian boxthorn		
**Nicotiana glauca*	tree tobacco		
Nicotiana simulans	native tobacco		
Nicotiana velutina	velvet tobacco		
Solanum ellipticum	velvet potato-bush		
Solanum esuriale	quena		
Solanum lacunarium	lagoon nightshade		
**Solanum nigrum*	black nightshade		
Scrophulariaceae			
Limosella curdieana var. 'curdieana'	large mudwort		
Stemodia florulenta	bluerod		
Acanthaceae			
Rostellularia adscendens ssp. *adscendens* var. *pogonanthera*	pink tongues		
Myoporaceae			
Eremophila freelingii	rock emubush		
Eremophila glabra ssp. *glabra*	tar bush		
Eremophila latrobei ssp. *glabra*	crimson emubush		
Eremophila longifolia	weeping emubush		
Eremophila maculata var. *maculata*	spotted emubush		
Eremophila oppositifolia var. *oppositifolia*	opposite-leaved emubush		
Eremophila serrulata	green emubush		
Myoporum montanum	native myrtle		
Plantaginaceae			
Plantago drummondii	dark plantain		
Campanulaceae			
Wahlenbergia communis	tufted bluebell		
Wahlenbergia tumidifructa	swollen-fruit bluebell		
Goodeniaceae			
Goodenia cycloptera	serrated goodenia		
Goodenia fascicularis	silky goodenia		
Goodenia gibbosa			
Goodenia lunata	stiff goodenia		
Goodenia pinnatifida	cut-leaf goodenia		
Goodenia pusilliflora	small-flower goodenia		
Scaevola collaris			
Scaevola spinescens	spiny fanflower		
Compositae			
Anemocarpa podolepidium	rock everlasting		
Angianthus brachypappus	spreading angianthus		

Species by family in Engler order		AUS[1]	SA[2]
Brachycome campylocarpa	large white daisy		
Brachycome ciliaris var. *ciliaris*	variable daisy		
Brachycome ciliaris var. *lanuginosa*	woolly variable daisy		
Brachycome dichromosomatica var. *dichromosomatica*	large hard-head daisy		
Brachycome eriogona		(3R)	R
Brachycome lineariloba	hard-head daisy		
Calocephalus platycephalus	western beauty-heads		
Calocephalus sp.	beauty-heads		
Calotis hispidula	hairy burr-daisy		
Calotis multicaulis	woolly-headed burr-daisy		
Calotis plumulifera	woolly-headed burr-daisy		
**Carthamus lanatus*	saffron thistle		
**Centaurea melitensis*	Malta thistle		
Centipeda cunninghamii	common sneezeweed		
Centipeda thespidioides	desert sneezeweed		
Chrysocephalum pterochaetum	shrub everlasting		
Dichromochlamys dentatifolius			
Dimorphocoma minutula			
Elachanthus pusillus	elachanth		
Epaltes australis	spreading nut-heads		
Eriochlamys behrii	woolly mantle		
Glossogyne tannensis	native cobbler's-pegs		
Gnaphalium diamantinense	Diamantina cudweed		
Gnephosis arachnoidea	spidery button-flower		
Gratwickia monochaeta		(3R)	R
**Helianthus annuus*	sunflower		
Hyalosperma semisterile	orange sunray		
Isoetopsis graminifolia	grass cushion		
Ixiochlamys cuneifolia	Silverton daisy		
Ixiochlamys nana	small fuzzweed		
Ixiolaena chloroleuca	pale plover-daisy		
Ixiolaena leptolepis	narrow plover-daisy		
Lemooria burkittii	wires-and-wool		
Leucochrysum molle	hoary sunray		
Microseris lanceolata	yam daisy		
Minuria annua	annual minuria		
Minuria cunninghamii	bush minuria		
Minuria denticulata	woolly minuria		
Minuria integerrima	smooth minuria		
Minuria leptophylla	minnie daisy		
Myriocephalus pluriflorus	inland woolly-heads		
Othonna gregorii	fleshy groundsel		
Picris angustifolia ssp. *angustifolia*	coast picris		
Pluchea rubelliflora			
Podolepis capillaris	wiry podolepis		
Podolepis davisiana	button podolepis		
Polycalymma stuartii	poached-egg daisy		
Pseudognaphalium luteoalbum	Jersey cudweed		
Pycnosorus pleiocephalus	soft billy-buttons		
Rhodanthe floribunda	white everlasting		
Rhodanthe microglossa	clustered everlasting		

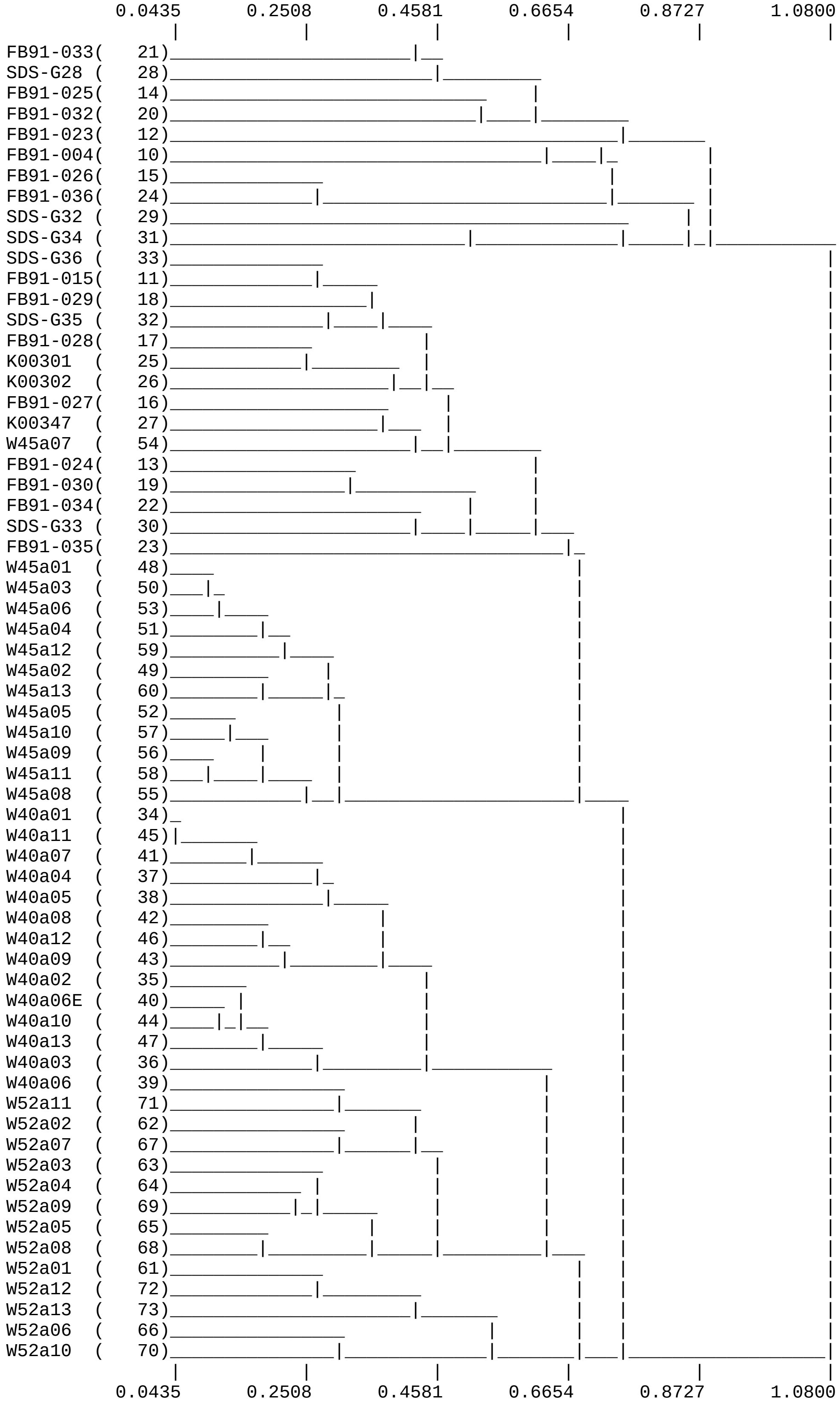
Species by family in Engler order		AUS[1]	SA[2]
Rhodanthe moschata	musk daisy		
Rhodanthe pygmaea	pigmy daisy		
Rhodanthe stricta	slender everlasting		
Rhodanthe uniflora	woolly daisy		
Schoenia ramosissima	dainty everlasting		
Senecio glossanthus	annual groundsel		
Senecio lautus	variable groundsel		
**Sonchus oleraceus*	common sow-thistle		
**Sonchus tenerrimus*	clammy sow-thistle		
Streptoglossa liatroides	Wertaloona daisy		
Trichanthodium skirrophorum	woolly yellow-heads		
Vittadinia cervicularis var. *cervicularis*	waisted New Holland daisy		
Vittadinia eremaea	desert New Holland daisy		
Vittadinia pterochaeta	rough New Holland daisy		
Juncaginaceae			
Triglochin calcitrapum	spurred arrowgrass		
Liliaceae			
Arthropodium fimbriatum	nodding vanilla-lily		
Bulbine alata	winged bulbine-lily		
Burchardia umbellata	milkmaids		
Thysanotus exiliflorus	inland fringe-lily		
Wurmbea centralis ssp. *australis*	inland Nancy		
Agavaceae			
**Agave americana* var. *americana*	century plant		
Amaryllidaceae			
Crinum flaccidum	Murray lily		
Juncaceae			
Juncus bufonius	toad rush		
Gramineae			
Agrostis avenacea var. *avenacea*	common blown-grass		
**Alopecurus geniculatus*	marsh fox-tail		
Aristida contorta	curly wire-grass		
Aristida holathera var. *holathera*	tall kerosene grass		
Aristida nitidula	brush three-awn		
Aristida obscura	brush three-awn		
Astrebla pectinata	barley Mitchell-grass		
**Avena barbata*	bearded oat		
**Avena fatua*	wild oat		
Bromus arenarius	sand brome		
**Bromus diandrus*	great brome		
Chloris pectinata	comb windmill grass		
**Chloris virgata*	feather-top Rhodes grass		
**Critesion murinum* ssp. *glaucum*	blue barley-grass		
Cymbopogon ambiguus	lemon-grass		
Dactyloctenium radulans	button-grass		
Danthonia caespitosa	common wallaby-grass		
Danthonia setacea var. *setacea*	small-flower wallaby-grass		
Dichanthium sericeum ssp. *humilius*	annual silky blue-grass		
Dichanthium sericeum ssp. *sericeum*	silky blue-grass		
Digitaria ammophila	spider grass		
Digitaria brownii	cotton panic-grass		

Species by family in Engler order		AUS[1]	SA[2]
Digitaria ciliaris	summer grass		
Digitaria coenicola	spider grass		
**Digitaria sanguinalis*	crab grass		
Enneapogon avenaceus	common bottle-washers		
Enneapogon caerulescens var. *caerulescens*	blue bottle-washers		
Enneapogon cylindricus	jointed bottle-washers		
Enneapogon nigricans	black-head grass		
Enteropogon acicularis	umbrella grass		
Enteropogon ramosus	umbrella grass		
Eragrostis australasica	cane-grass		
**Eragrostis cilianensis*	stink grass		
Eragrostis dielsii var. *dielsii*	mulka		
Eragrostis eriopoda	woollybutt		
Eragrostis leptocarpa	drooping love-grass		
Eragrostis parviflora	weeping love-grass		
Eragrostis setifolia	bristly love-grass		
Eragrostis xerophila	knotty-butt neverfail		
Eriachne mucronata	mountain wanderrie		
Eriachne ovata	swamp wanderrie		
Eriochloa australiensis	Australian cupgrass		
Eriochloa pseudoacrotricha	perennial cupgrass		
Eulalia aurea	silky brown-top		
Iseilema vaginiflorum	red Flinders-grass		
**Lamarckia aurea*	toothbrush grass		
Panicum decompositum var. *decompositum*	native millet		
Panicum laevinode			
Paspalidium basicladum			
Paspalidium constrictum	knotty-butt paspalidium		
Paspalidium jubiflorum	Warrego summer-grass		
**Pennisetum clandestinum*	kikuyu		
**Polypogon monspeliensis*	annual beard-grass		
**Rostraria pumila*	tiny bristle-grass		
**Schismus barbatus*	Arabian grass		
Setaria dielsii	Diel's pigeon-grass		
**Setaria italica*	fox-tail millet		
Sporobolus actinocladus	ray grass		
Sporobolus caroli	yakka grass		
Stipa elegantissima	feather spear-grass		
Stipa nitida	Balcarra spear-grass		
Stipa scabra ssp. *scabra*	rough spear-grass		
Themeda triandra	kangaroo grass		
Triraphis mollis	purple plume grass		
Urochloa praetervisa	large arm-grass		
Cyperaceae			
Cyperus alterniflorus 'Oodnadatta form'	umbrella flat-sedge		
Cyperus bulbosus	bulbous flat-sedge		
Cyperus difformis	variable flat-sedge		
**Cyperus eragrostis*	drain flat-sedge		
Cyperus exaltatus	splendid flat-sedge		
Cyperus gilesii	Giles' flat-sedge		
Cyperus gymnocaulos	spiny flat-sedge		

Species by family in Engler order		AUS[1]	SA[2]
Cyperus rigidellus	dwarf flat-sedge		
**Cyperus rotundus* ssp. *rotundus*	nut-grass		
Cyperus squarrosus	bearded flat-sedge		
Cyperus victoriensis	yelka		
Eleocharis pallens	pale spike-rush		
Fimbristylis dichotoma	common fringe-rush		
Isolepis australiensis	southern club-rush		
Isolepis fluitans	floating club-rush		
Schoenoplectus dissachanthus	inland club-rush		

* Introduced species
(1) National (Briggs and Leigh 1995) conservation rating
(2) State conservation rating

D1.8 Attachment C: Dendrogram from the PATN Analysis of Sites from Similar Land Systems



Explanation of site numbering:

- SDS represents composite floristic group data from the Stony Deserts Survey (Brandle 1998). The second part of the row label shows the SDS group number.
- FB91 represents unpublished data from the Badman (1992) survey.
- Site numbers prefixed 'K' represent unpublished data from the Badman (2001) survey.
- Site numbers prefixed 'W' represent data from the August 2001 survey.

D1.9 Attachment D: Part of a Dendrogram from the PATN Analysis of Floristic Data from Sites Across the Kingoonya SCD

Less than half of the complete dendrogram is shown here. Data from the remaining sites has been omitted because it is dissimilar to any sites on the Arcoona Tableland.

```
          0.0968      0.5014      0.9061      1.3107      1.7154      2.1200
               |           |           |           |           |           |
DT95-02 (    1)______________
DT95-06 (    3)_____________|____
DT95-05 (    2)_______________  |
K00-221 (  284)______________|__|____
K00-133 (  196)_____________        |
K00-137 (  200)____________|________|
K00-241 (  304)____________________||__
DT95-18 (   14)____________           |
K00-204 (  267)___________|           |
K00-320 (  383)__________||____       |
DT95-22 (   17)_________      |       |
DT95-23 (   18)________|______|       |
DT95-24 (   19)______________||__     |
W52a06  (  443)______           |     |
W52a10  (  447)_____|___________|__   |
FB91-015(   39)______________     |   |
FB91-024(   48)__________   |     |   |
FB91-030(   54)_________|___|_    |   |
FB91-025(   49)______________|    |   |
FB91-034(   58)_____________||___ |   |
FB91-035(   59)________________ | |   |
K00-299 (  362)________       | | |   |
W52a13  (  450)_______|___    | | |   |
K00-300 (  363)__________|____|_|_|__ |
K00-183 (  246)_________            | |
K00-198 (  261)________|_____       | |
K00-184 (  247)___________  |       | |
K00-185 (  248)__________|__|___    | |
K00-200 (  263)______________  |    | |
K00-212 (  275)_____________|__|__  | |
K00-201 (  264)_____________     |  | |
K00-209 (  272)____________|_____|__|_|__
FB91-004(   28)___________________      |
FB91-026(   50)_________         |      |
FB91-036(   60)________|_________|_     |
K00-194 (  257)_________________  |     |
K00-332 (  395)________________|__|_    |
FB91-032(   56)____________        |    |
FB91-033(   57)___________|________|__  |
K00-294 (  357)______________________|  |
K00-304 (  367)_____________________||__|___
K00-146 (  209)____________                |
K00-207 (  270)_______    |                |
K00-310 (  373)______|___ |                |
K00-313 (  376)_________|_|__              |
K00-235 (  298)_____________|_             |
K00-182 (  245)_____________ |             |
K00-312 (  375)_________   | |             |
K00-328 (  391)________|__ | |             |
K00-326 (  389)__________| | |             |
K00-334 (  397)_________||_| |             |
K00-314 (  377)___________||_|__           |
K00-157 (  220)__________      |           |
K00-158 (  221)_________|_____ |           |
K00-315 (  378)______________|_|__         |
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          0.0968      0.5014      0.9061      1.3107      1.7154      2.1200
               |           |           |           |           |           |
K00-329 (  392)_________         |         |
K00-331 (  394)________|_        |         |
K00-330 (  393)_________|________|         |
K00-336 (  399)__________________|_________|
K00-202 (  265)___________                 |
K00-342 (  405)__________|______           |
K00-341 (  404)________________|_          |
K00-337 (  400)__________       |          |
K00-338 (  401)_________|_____  |          |
K00-340 (  403)______________|__|__________|_______
DT95-07 (    4)______________                     |
DT95-09 (    5)_____________|____                 |
DT95-16 (   12)____________     |                 |
DT95-17 (   13)___________|____ |                 |
K00-210 (  273)___________    | |                 |
K00-211 (  274)__________|____|_|                 |
K00-214 (  277)_________________|___              |
K00-216 (  279)______________      |              |
K00-343 (  406)_____________|__    |              |
K00-218 (  281)_______________|____|___           |
DT95-10 (    6)______________         |           |
DT95-31 (   24)_____________|___      |           |
DT95-28 (   22)___________     |      |           |
DT95-29 (   23)__________|_____|____  |           |
DT95-20 (   16)_____________       |  |           |
DT95-25 (   20)____________|_______|_ |           |
DT95-12 (    8)_____________        | |           |
DT95-13 (    9)________    |        | |           |
DT95-14 (   10)_______|____|____    | |           |
DT95-15 (   11)________________|____|_|______     |
DT95-11 (    7)______________               |     |
K00-142 (  205)_____________|_______        |     |
FB91-017(   41)____________________|______  |     |
DT95-19 (   15)___________________       |  |     |
DT95-26 (   21)_______________   |       |  |     |
K00-335 (  398)______________|___|___    |  |     |
K00-188 (  251)___________          |    |  |     |
K00-189 (  252)__________|_________ |    |  |     |
K00-203 (  266)___________________|_|___ |  |     |
K00-339 (  402)________________________|_|__|_____|_____
FB91-027(   51)_________                               |
K00-284 (  347)________|_                              |
K00-347 (  410)_________|___                           |
FB91-028(   52)_______     |                           |
FB91-029(   53)______|     |                           |
K00-301 (  364)_____||___  |                           |
K00-302 (  365)_________|__|                           |
W52a01  (  438)________   ||                           |
W52a12  (  449)_______|___||_                          |
W40a01  (  411)_            |                          |
W40a07  (  418)|__          |                          |
W40a11  (  422)__|__        |                          |
W40a04  (  414)____|___     |                          |
W45a07  (  431)_______|___  |                          |
W40a02  (  412)__        |  |                          |
W40a03  (  413)_|_____   |  |                          |
W40a06E (  417)__    |   |  |                          |
W40a10  (  421)_|__  |   |  |                          |
W40a13  (  424)___|__|_  |  |                          |
W40a06  (  416)_______|  |  |                          |
W40a08  (  419)____   |  |  |                          |
W40a09  (  420)___|   |  |  |                          |
W40a12  (  423)__||___|__|__|_                         |
W52a02  (  439)_______       |                         |
W52a07  (  444)______|_____  |                         |
W52a03  (  440)_____      |  |                         |
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W52a04  (  441)____|_     |  |                         |
W52a11  (  448)_____|__   |  |                         |
W52a05  (  442)_____  |   |  |                         |
W52a08  (  445)___ |  |   |  |                         |
W52a09  (  446)__|_|__|___|__|_                        |
W45a01  (  425)__             |                        |
W45a03  (  427)_|             |                        |
W45a06  (  430)||__           |                        |
W45a02  (  426)___|__         |                        |
W45a05  (  429)___  |         |                        |
W45a10  (  434)__|__|         |                        |
W45a09  (  433)__  ||         |                        |
W45a11  (  435)_|__||         |                        |
W45a12  (  436)____||_        |                        |
W45a08  (  432)_____ |        |                        |
W45a13  (  437)____|_|_       |                        |
W45a04  (  428)_______|_______|___                     |
W40a05  (  415)__________________|__________           |
K00-156 (  219)____________                |           |
K00-213 (  276)___________|___             |           |
K00-319 (  382)_________     |             |           |
K00-333 (  396)________|_    |             |           |
K00-325 (  388)_________|____|             |           |
K00-324 (  387)_____________||___          |           |
K00-215 (  278)____________     |          |           |
K00-318 (  381)___________|___  |          |           |
K00-321 (  384)________      |  |          |           |
K00-323 (  386)_______|______|  |          |           |
K00-322 (  385)_____________||__|__        |           |
K00-186 (  249)_______            |        |           |
K00-191 (  254)____  |            |        |           |
K00-192 (  255)___|__|_           |        |           |
K00-190 (  253)_______|______     |        |           |
K00-193 (  256)_________    |     |        |           |
K00-195 (  258)________|    |     |        |           |
K00-199 (  262)________|____|___  |        |           |
K00-205 (  268)________________|  |        |           |
K00-316 (  379)___________    ||  |        |           |
K00-345 (  408)______    |    ||  |        |           |
K00-346 (  409)_____|____|____||  |        |           |
K00-317 (  380)______________|||__|______  |           |
K00-196 (  259)______________           |  |           |
K00-197 (  260)_____________|___________|__|___________|____________________
FB91-001(   25)_____________                                               |
K00-143 (  206)____________|_____                                          |

               |           |           |           |           |           |
          0.0968      0.5014      0.9061      1.3107      1.7154      2.1200
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Explanation of site numbering:

- Site numbers prefixed ‘DT’ represent data from Badman (1995c).
- Site numbers prefixed ‘K’ represent data from Badman (2001).
- Site numbers prefixed ‘W’ represent data from the August 2001 survey.

D1.10 Attachment E: Floristic Composition of Vegetation of the Arcoona Tableland

	Jessup	Brandle (1998)[1] group no.				Badman[3]	This survey Site no.		
Species	**(1951)**	**28[2]**	**34**	**35**	**36**	**(2001)**	**40a**	**45a**	**52a**
Abutilon fraseri						R			
Abutilon halophilum	FC	C		FC	FC	U	U	U	U
Abutilon leucopetalum		+							
Abutilon otocarpum		+				R			
Acacia aneura		+				R			
Acacia cibaria		U							
Acacia ligulata			U			R			
Acacia oswaldii		+				R			
Acacia papyrocarpa			U						
Acacia rigens	R								
Acacia stowardii		+							
Acacia tetragonophylla		+				U			
Acacia victoriae		+				U			
Acetosa vesicaria		+				R			
Agrostis sp.		+							
Alectryon oleifolius		+				R			
Alopecurus geniculatus								U	U
Alternanthera denticulata		+						U	R
Alyssum linifolium								R	U
Amaranthus grandiflorus		+							
Amaranthus macrocarpus		+							
Amaranthus mitchellii		+							
Amyema maidenii		+				R			
Amyema miquelii		+							
Amyema miraculosum		+							
Amyema preissii		+				U			
Amyema quandang		+							
Anacampseros australiana	VR	+				R			
Anagallis arvensis		+				R			
Anemocarpa podolepidium						R			
Arabidella nasturtium		+				U	C	C	FC
Aristida anthoxanthoides	R	+							
Aristida contorta			FC			U			R
Aristida nitidula		+				R			
Arthropodium fimbriatum		+							
Asperula gemella		+							
Astrebla pectinata	VC	C		C		FC		C	U
Atriplex angulata					U			FC	
Atriplex eardleyae						R			
Atriplex fissivalvis	VR	+				U			
Atriplex holocarpa					U	U	C	C	C
Atriplex limbata		+							
Atriplex lindleyi	R	FC	U	FC		U	U	U	U

Species	Jessup (1951)	Brandle (1998)[1] group no. 28[2]	34	35	36	Badman[3] (2001)	This survey Site no. 40a	45a	52a
Atriplex nummularia ssp. *omissa*		U			U				
Atriplex spongiosa	FR	FC		U		U		U	
Atriplex stipitata		+							
Atriplex vesicaria	D	C	D	D	D	D	D	D	D
Blennodia canescens		+				U			
Boerhavia coccinea		+							
Boerhavia dominii		+							
Boerhavia schomburgkiana		+							
Brachycome ciliaris		+				U			
Brachycome dichromosomatica		+				U	C	C	C
Brachycome eriogona		+							
Brachycome lineariloba		FC				U	U	U	U
Brassica tournefortii		+				U		U	
Bromus arenarius		FC				U			FC
Bulbine alata						U	R	U	U
Bulbine semibarbata		FC							
Burchardia umbellata		+							
Calandrinia eremaea		+					R	R	U
Calandrinia polyandra		+							
Calandrinia remota		+				U			
Calandrinia volubilis		+							
Calotis hispidula	FR	+				U	C	C	C
Calotis plumulifera		+							U
Carrichtera annua		+				U			
Carthamus lanatus						U			
Casuarina pauper					U	U			
Centaurea melitensis		+				U			
Centaurium spicatum	R					U			
Centipeda cunninghamii						U			
Centipeda sp.							U	FC	U
Centipeda thespidioides		+				U			
Cheilanthes lasiophylla		+				U			
Chenopodium auricomum							U		
Chenopodium desertorum		+							
Chenopodium melanocarpum		+							
Chenopodium nitrariaceum		+					U		
Chenopodium pumilio		+							
Chloris truncata	R	+							
Chrysocephalum pterochaetum		+							
Citrullus colocynthis		+							
Citrullus lanatus		+							
Convolvulus erubescens		+						R	
Convolvulus remotus		+							
Crassula colorata						U		U	U
Crinum flaccidum		+				U			
Critesion murinum						U			
Cucumis myriocarpus								R	
Cullen australasicum					FC		?U	?FC	?FC
Cullen cinereum		+							

Species	Jessup (1951)	Brandle (1998)[1] group no. 28[2]	34	35	36	Badman[3] (2001)	This survey Site no. 40a	45a	52a
Cullen graveolens		C				U			
Cullen pallidum		+							
Cullen patens						U			
Cullen sp.	C						U	FC	FC
Cymbopogon ambiguus						U			
Cyperus bulbosus		+							
Cyperus gilesii		+							
Cyperus rigidellus		+							
Dactyloctenium radulans	FR	+							
Danthonia caespitosa		+							
Danthonia setacea		+							
Daucus glochidiatus	R	FC				U	FC	FC	FC
Dichanthium sericeum		+				U		R	
Digitaria ammophila		+							
Digitaria coenicola		+							
Dimorphocoma minutula								U	
Disphyma crassifolium		+							
Dissocarpus biflorus	VR	+							
Dissocarpus biflorus var. *biflorus*						U		U	U
Dissocarpus biflorus var. *villosus*									U
Dissocarpus paradoxus	R	C		C	U	C	C	C	FC
Dodonaea lobulata		+				U			
Echium plantagineum		+				U			
Einadia nutans		+					R		
Eleocharis pallens		FC						R	
Enchylaena tomentosa		+				U			
Enneapogon avenaceus	R		FC						
Enneapogon cylindricus			FC				U		
Enneapogon polyphyllus		U							
Enteropogon ramosus		+							
Epaltes cunninghamii	R								
Eragrostis australasica	FR	FC				U	FC	FC	U
Eragrostis dielsii	R	+				U			
Eragrostis falcate	VC								
Eragrostis setifolia	VC	FC	C	D	FC	C	FC	FC	FC
Eremophila duttonii			U						
Eremophila glabra		+							
Eremophila latrobei		+							
Eremophila longifolia		+				U			
Eremophila maculata		+							
Eremophila oppositifolia		+				U			
Eremophila serrulata		+				U			
Eriochiton sclerolaenoides	VR	+							
Eriochlamys behrii		+							
Eriochloa australiensis	FR	+							
Erodium angustilobum		+				U			
Erodium aureum						U	FC	FC	U
Erodium cicutarium		FC				U	C	C	FC
Erodium crinitum		+							C

	Jessup	Brandle (1998)[1] group no.				Badman[3]	This survey Site no.		
Species	**(1951)**	**28[2]**	**34**	**35**	**36**	**(2001)**	**40a**	**45a**	**52a**
Erodium cygnorum	FC					U			
Eucalyptus camaldulensis		+							
Eulalia aurea	FC								
Eulalia aurea		+							
Euphorbia australis		+							
Euphorbia drummondii		+						R	
Euphorbia parvicaruncula		+							
Euphorbia stevenii	FR	FC				U	FC	FC	U
Euphorbia tannensis		+							
Exocarpos aphyllus		+							
Frankenia plicata		FC							
Frankenia serpyllifolia	R	FC		C	C	C	FC	C	FC
Glycine canescens						U			
Gnaphalium diamantinense		+							
Gnephosis arachnoidea		+				U		U	U
Gnephosis tenuissima		+							
Goodenia cycloptera		+							
Goodenia fascicularis		+							
Goodenia gibbosa		+							
Goodenia lunata		+							
Goodenia pinnatifida	FC					U			
Goodenia pusilliflora									U
Gratwickia monochaeta		+							
Gunniopsis calva		+							
Gunniopsis papillata		+							
Gunniopsis quadrifida			FC		U	U			
Gypsophila tubulosi		+							
Hakea leucoptera			U						
Halosarcia indica	C								
Halosarcia pergranulata						U			
Halosarcia sp.						U			
Harmsiodoxa puberula		+							
Herniaria cinerea		+							
Hyalosperma semisterile									U
Iseilema vaginiflorum	VR	+							
Isoetopsis graminifolia									U
Ixiochlamys cuneifolia		+							
Ixiochlamys nana									R
Ixiolaena chloroleuca		FC						FC	U
Ixiolaena leptolepis	D[4]	C		U	U	FC		U	
Lamarckia aurea		+							
Lemooria burkittii									U
Lepidium oxytrichum	R					U	R	U	U
Lepidium papillosum		+							
Lepidium phlebopetalum						U	FC	FC	FC
Lepidium rotundum		+							
Lepidium sagittulatum							R		R
Leucochrysum molle						U			
Limonium lobatum		+							

	Jessup	Brandle (1998)[1] group no.				Badman[3]	This survey Site no.		
Species	**(1951)**	**28[2]**	**34**	**35**	**36**	**(2001)**	**40a**	**45a**	**52a**
Limosella curdieana								U	U
Lotus cruentus	C	FC				U	FC	FC	FC
Lycium australe		+				U			
Lysiana exocarpi		+							
Maireana aphylla	R	C	FC	U		U	U	C	FC
Maireana appressa	VR	+				U	FC	FC	FC
Maireana astrotricha	VR		D		U	FC	U		C
Maireana cannonii						U			
Maireana ciliata	VR								
Maireana coronata		+							
Maireana eriantha	VR			FC		U			U
Maireana georgei	VR	+				U	U	U	U
Maireana integra						U			FC
Maireana microcarpa		+							
Maireana oppositifolia		+							
Maireana pentatropis		+							
Maireana planifolia		+							
Maireana pyramidata			C			U	U		
Maireana sedifolia						R			
Maireana spongiocarpa	VR	+				U		U	
Malacocera albolanata						R			
Malacocera tricornis		+					U		
Malvastrum americanum		+							
Marsilea costulifera							R		
Marsilea drummondii	R	+				U	U	U	U
Marsilea exarata								R	
Marsilea hirsute	R	+							
Medicago polymorpha		+				R			
Melaleuca xerophila						U			
Menkea crassa						U			
Microseris lanceolata									U
Minuria annua							U	U	R
Minuria cunninghamii		FC			C	C	FC	FC	FC
Minuria denticulata	FC	FC					R		
Minuria integerrima		+							
Minuria leptophylla	C								
Minuria sp.				FC					
Muehlenbeckia florulenta		U					U		
Myoporum montanum		+				U			
Myosurus minimus		+						R	R
Neobassia proceriflora		+							
Nicotiana simulans								R	
Nicotiana velutina		+					R	U	
Omphalolappula concava									U
Osteocarpum acropterum		+		U		U			
Osteocarpum dipterocarpum	R	FC				U	FC	FC	FC
Othonna gregorii		+				U			U
Oxalis perennans		+				R			
Panicum decompositum	VC	+							

	Jessup	Brandle (1998)[1] group no.				Badman[3]	This survey Site no.		
Species	**(1951)**	**28[2]**	**34**	**35**	**36**	**(2001)**	**40a**	**45a**	**52a**
Paspalidium basicladum		+							
Paspalidium constrictum		+				U			
Paspalidium sp.	FC								
Phlegmatospermum cochlearinum						U	FC	U	FC
Pimelea microcephala		+							
Pimelea simplex		+							
Pittosporum phylliraeoides			U			U			U
Plagiobothrys plurisepaleus							U	F	U
Plantago drummondii	FR	FC				U	FC	FC	FC
Podolepis capillaries		+				U			
Podolepis davisiana		+				U	FC		FC
Polycalymma stuartii		+				R			
Portulaca oleracea	R	FC				U	U	U	
Prostanthera striatiflora		+							
Ptilotus exaltatus		+							
Ptilotus nobilis		+							
Ptilotus obovatus		+				R			
Ptilotus parvifolius		+				U			
Ptilotus sessilifolius						R			
Ptilotus sp.	VR								
Pycnosorus pleiocephalus		+				U			
Ranunculus pentandrus	R						U	U	U
Rhagodia spinescens			FC			FC			FC
Rhodanthe floribunda	R	+					U	U	
Rhodanthe microglossa		FC				U		FC	U
Rhodanthe moschata		+				U			
Rhodanthe pygmaea		+				U			
Rhodanthe stricta	FC	+				U	FC	FC	FC
Rhodanthe uniflora		+					FC	FC	FC
Rhyncharrhena linearis		+							
Rostellularia adscendens		+				U			
Rostraria pumila		+				U		U	U
Rumex crystallinus						R			
Salsola kali		FC	FC			U	U	U	U
Santalum lanceolatum		+				U			
Sarcostemma viminale	VR	+				U			FC
Sarcozona praecox	R[5]					U			
Sauropus trachyspermus		+							
Schismus barbatus		+							R
Sclerolaena brachyptera	FC	FC	C	FC	FC	C	FC	FC	U
Sclerolaena cuneata		C				FC			
Sclerolaena decurrens			U			U			
Sclerolaena diacantha		+						FC	
Sclerolaena divaricata	R			D	C	C	C	FC	U
Sclerolaena holtiana						R			
Sclerolaena intricate				C	FC	FC	FC	FC	U
Sclerolaena lanicuspis	VR		U						
Sclerolaena obliquicuspis			U			FC			

	Jessup	Brandle (1998)[1] group no.				Badman[3]	This survey Site no.		
Species	**(1951)**	**28[2]**	**34**	**35**	**36**	**(2001)**	**40a**	**45a**	**52a**
Sclerolaena parallelicuspis		+						U	
Sclerolaena patenticuspis				U					
Sclerolaena tatei						R			
Sclerolaena tricuspis	VR								
Sclerolaena uniflora	R					U			
Sclerolaena ventricosa	FR	D	C	C	FC	C	C	C	C
Sclerostegia medullosa		FC	U	C	D		C		C
Sclerostegia sp.				U		C			
Sclerostegia tenuis	C				U			C	
Senecio glossanthus		FC				U	FC	FC	FC
Senna artemisioides ssp. *coriacea*					U	U			
Senna artemisioides ssp. *filifolia*						R			
Senna artemisioides ssp. *helmsii*			U						
Senna artemisioides ssp. *petiolaris*		+				R			
Senna artemisioides ssp. *sturtii*		+							
Sida corrugata	VR	+							
Sida fibulifera		+				U		FC	
Sida filiformis		+							
Sida intricate	VR	+							
Sida petrophila		+				R			
Sida trichopoda	C	C						FC	
Sisymbrium erysimoides		+				R			
Solanum ellipticum		+				U			R
Solanum esuriale		+					U		
Solanum lacunarium						R			
Solanum nigrum						R			
Solanum quadriloculatum		+							
Sonchus oleraceus		+				R			U
Sonchus tenerrimus		FC				U		R	
Sporobolus actinocladus	VC		FC	FC		FC	U	U	
Stackhousia clementii		+				R			
Stemodia florulenta		+				U			
Stenopetalum lineare									U
Stipa nitida	R	+				U			
Stipa scabra		+							
Streptoglossa cylindriceps		+							
Swainsona phacoides		+				U			
Swainsona stipularis	FC	+				U		R	
Tetragonia eremaea						U	R	U	FC
Tetragonia tetragonioides		+							
Teucrium racemosum	R	+					U	U	
Thysanotus baueri		+							R
Tragus australianus	R	+							
Trianthema triquetra	R	+					FC	FC	
Trichanthodium skirrophorum		+							
Triglochin calcitrapum						U		FC	FC
Trigonella suavissima	FR	+					U	U	FC

Species	Jessup (1951)	Brandle (1998)[1] group no. 28[2]	34	35	36	Badman[3] (2001)	This survey Site no. 40a	45a	52a
Tripogon loliiformis		+							
Vittadinia eremaea		+							
Vittadinia pterochaeta		+							
Wahlenbergia communis		+				U			
Wahlenbergia tumidifructa		+				U		U	U
Wurmbea centralis						R			
Zygophyllum ammophilum	R[6]	+							
Zygophyllum aurantiacum		+				U			
Zygophyllum compressum	R								
Zygophyllum crenatum		+							
Zygophyllum emarginatum		+				FC	C	C	C
Zygophyllum eremaeum	R	+				U			
Zygophyllum humillimum		+							
Zygophyllum iodocarpum						U	U	U	U
Zygophyllum prismatothecum						U			
Zygophyllum simile		+						FC	U
Zygophyllum sp.			U						

Species that occur only on sand dunes have been omitted.

Taxonomy has been updated where necessary to reflect current names. Subspecies and varieties have generally been omitted from this list unless their omission would cause confusion. These are given in Attachment B. Species that are not known from the Arcoona Tableland (from Brandle 1998) have been omitted.

D = Dominant, C = Common, FC = Fairly common, FR = Fairly rare, R = Rare, VR = Very rare (all from Jessup 1951), U = Uncommon

(1) Species are listed as Common if they are reported as occurring at >50% of sites or dominating at >15% of sites. Other species named in the group lists are regarded as being Fairly Common. Species that are listed for the Arcoona Tableland but are not present in the group lists are regarded here as being Uncommon.

(2) + indicates that the taxon was recorded by Brandle on the Arcoona Tableland, but not necessarily in group 28.

(3) Species are listed as Common if they are reported as occurring at >50% of sites and with a substantial cover. Rare indicates that only a small number of plants was found at a single site.

(4) *Ixiolaena leptolepis* in Jessup's list includes *Ixiolaena chloroleuca*.

(5) The taxon referred to by Jessup as *Mesembryanthemum aequilaterale* is thought to be *Sarcozona praecox.*

(6) Includes both *Zygophyllum emarginatum* and *Zygophyllum simile.*

D1.11 Attachment F: Non-vascular Plants of the Arcoona Tableland

	Soil			Rock		
	40a	45a	52a	40a	45a	52a
Lichens						
?Acarospora sp.	✓	✓				Silcrete
Acarospora citrina (Taylor) Zahlbr. ex Rech.				Quartzite	Quartzite	Quartzite
Buellia sp.				Quartzite		Silcrete
Caloplaca sp.		✓				Silcrete
Collema sp.	✓	✓	✓			
Endocarpum simplicatum (Nyl.) Nyl.		✓	✓			
Endocarpon sp. (sterile)			✓			
Endocarpon sp. 1	✓		✓			
Endocarpon sp. 2	✓					
Lecidea sp.				Silcrete		Silcrete
Neofuscelia sp. 1						Quartzite & silcrete
Neofuscelia sp. 2 (isidiose)				Silcrete		Silcrete
Psora decipiens (Hedw.) Hoffin.	✓	✓	✓			
Psora sp. (sterile)	✓		✓			
Xanthoparmelia ?remanens (Elix) Elix & J. Johnst.				Quartzite	Quartzite	Quartzite & silcrete
Xanthoparmelia sp.						Silcrete
Xanthoparmelia sp. 1				Quartzite		Quartzite
Xanthoparmelia sp. 2				Quartzite		
Xanthoparmelia ?sp. 3				Silcrete	Quartzite	Silcrete
Liverworts						
Riccia crystallina L.	✓	✓	✓			
Riccia limbata Bisch.			✓(1)			
Mosses						
Desmatodon convolutus (Brid.) Grout	✓		✓			
Didymodon torquatus (Taylor) Catches.			✓(1)			
?Pterygoneurum sp.	✓		✓			

(1) Collected at Koolymilka Creek, Lake Koolymilka

Appendix D2
Fauna

A fauna survey was undertaken by Halliburton KBR in August 2001. This appendix is a report which summarises the results of the field work and supports the information presented in Chapter 9.

D2.1 Introduction

This report provides a summary of the fauna survey and assessment work undertaken for the proposal. It provides detailed information on the field assessment of the fauna at each of the three potential sites (40a, 45a and 52a) previously selected for the repository. In addition, it reviews the findings and conclusions of this work in relation to a predictive fauna model for the region, the Arcoona Tableland and the project area.

D2.2 Approvals

Two periods of field work were undertaken. The initial work was in August 2001 and the second was in October 2001. Prior to going into the field on each occasion, all relevant landholders were contacted and the approval of each was obtained in order to access the sites and to undertake the survey. The Defence Regional Environmental Officer indicated that an Environmental Certificate of Compliance was not required for the field work (M Donaghey, Defence Corporate Services & Infrastructure Centre SA, pers. comm., July 2001)

The Commonwealth indicated that Aboriginal heritage approvals for assessment activities involving ground disturbance were only current for the land within each of the 1.5 x 1.5 km sites. In addition, should Aboriginal heritage sites be noted within each site, then these were to be avoided during the field activities. Subsequently, this was applicable at Site 52a.

A ‘Permit to Undertake Scientific Research’ for the project was obtained from the Department for Environment and Heritage (SA DEH) for the project (Permit No. E24482). Wildlife Animal Ethics Committee approval was obtained as Licence No. 88.

D2.3 Methods and Materials

In many cases, the difference between recording the presence or absence of an animal species is due to the method and/or material used in the survey for the species. Therefore, detailed methods and materials are provided to facilitate monitoring and reproducibility by future surveys.

The following faunal groups were formally surveyed at each of the three sites:

- terrestrial mammals
- bats
- birds
- reptiles and amphibians
- macro-invertebrates (primarily ants and spiders).

In addition, a number of reptiles and invertebrates were observed and collected elsewhere on the Arcoona Tableland, including access roads.

Following a reconnaissance of each site and adjacent areas during August 2001, three major 'fixed' assessment areas were selected for each site, i.e. the site stratification adopted for the survey was targeted and non-random. Ground trapping areas were selected to assess all key, representative habitats and ecotones between habitats at each of the sites. Surveys for bats use different methods (harp traps, mist nets and call recording) and, by necessity, consider a wider range of locations to assess bat species. The location of fauna survey sites is presented in Figures D2.1 and D2.2. Figures D2.3–D2.5 illustrate the trapping locations for each of the sites.

A detailed analysis of the methods and materials used for the survey is presented in the following sections. Field survey location data are provided in Table D2.1. A range of standard and modified survey methods and materials were used during the survey for fauna. In general, these were based on the Biological Survey of South Australia Guidelines (Department for Environmental Heritage 2000) and Standard Operating Procedures with reference to Read and Moseby (2001), Moseby and Read (2001), and past experience of fauna surveys in this and similar regions of Australia.

TABLE D2.1 Fauna survey locations

Proposed site	Trapping site (TS)(1)	Latitude	Longitude
40a Arcoona	TS 1	31.21056°S	137.0508°E
	TS 2	31.20108°S	137.0521°E
	TS 3	31.20118°S	137.0457°E
	BS 1	31.1081°S	137.0315°E
	BS 2	31.1486°S	137.0420°E
	BS 3	31.2128°S	136.9514°E
	BS 4	31.2410°S	136.9436°E
45a Andamooka	TS 1	30.82528°S	137.1578°E
	TS 2	30.83078°S	137.1564°E
	TS 3	30.82402°S	137.145°E
	BS 1	30.7658°S	137.0971°E
52a Woomera	TS 1	30.96039°S	136.4268°E
	TS 2	30.83078°S	137.1563°E
	TS 3	30.82398°S	137.145°E
	BS 1	30.9493°S	136.4239°E
	BS 2	30.9707°S	136.5367°E
	BS 3	30.9764°S	136.5420°E

(1) BS = bat survey site

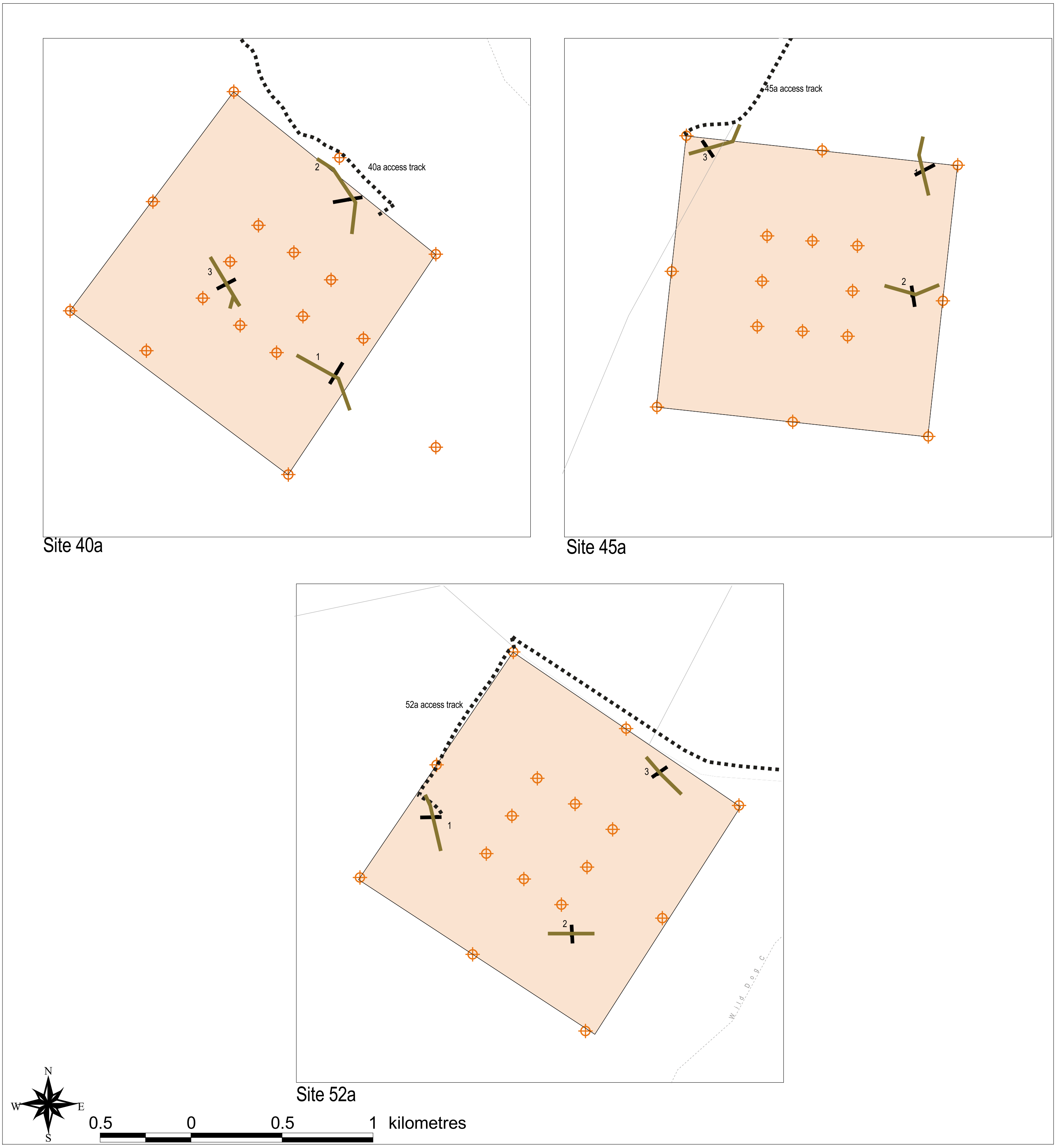
D2.3.1 Ground-dwelling Animals (especially Mammals and Reptiles)

Trapping

Ground-dwelling animals were surveyed using 5 L, 10 L and 20 L plastic buckets (pitfall traps) and medium and large rectangular aluminium box traps (Elliott traps).

The bait routinely used in Elliott traps during August and October consisted of:

- rolled oats (1 kg)
- crunchy peanut butter (0.5 kg)
- dry cat food (0.5 kg)
- canned cat food
- strongly flavoured and odiferous (Messmate) honey (0.5 kg)
- mixed dried fruit (0.25 kg)
- sardines in vegetable oil (0.40 kg)
- aniseed essence (25 ml)
- vanilla essence (20 ml).



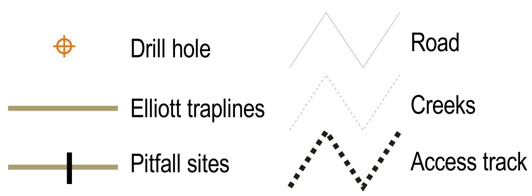


FIGURE D2.1

Fauna survey locations

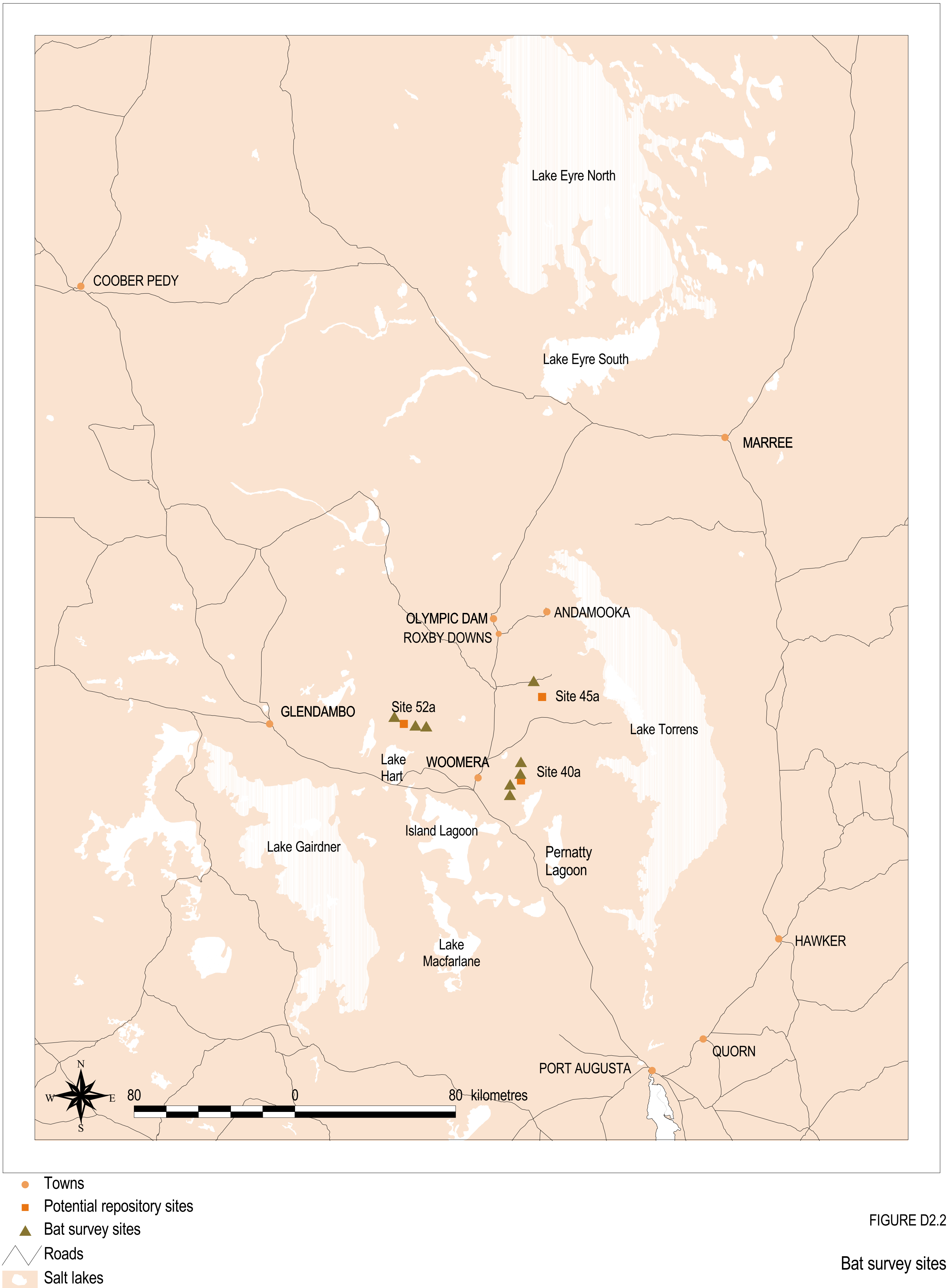


FIGURE D2.2

Bat survey sites

Photo 1 Fauna survey site No. 1

Photo 2 Fauna survey site No. 2

Photo 3 Fauna survey site No. 3

FIGURE D2.3
Site 45a fauna survey sites

Photo 1 Fauna survey site No. 1

Photo 2 Fauna survey site No. 2

Photo 3 Fauna survey site No. 3

FIGURE D2.4
Site 40a fauna survey sites

Photo 1 Fauna survey site No. 1

Photo 2 Fauna survey site No. 2

Photo 3 Fauna survey site No. 3

FIGURE D2.5
Site 52a fauna survey sites

This mixture was freshly prepared during the evenings prior to trapping. Dried lucerne pellets were used as an additional bait during the October trapping. Aniseed was selected in a conscious effort to attract any native mammals, such as dunnarts, which may have been present in the vicinity. Vanilla essence and lucerne pellets were used to maximise capture rates of rodents.

Elliott traps (up to 90) and pitfall traps (42) were used continuously at each of the three alternative sites during the survey periods, namely:

- August 7–14, 2001, 1182 Elliott and pitfall trap-nights
- October 5–13, 2001, 1696 Elliott and pitfall trap-nights.

Cross-transect trapping using a combination of pitfall traps and Elliott traps was used since it allowed assessment of a relatively large area and for sampling of all major habitats and ecotones represented in a site.

The methodologies used during the survey were as follows:

- Pitfall lines (transects) were placed in an orientation which provided maximum sampling of the target habitat (e.g. gilgai, gibber or canegrass). Ten 20 L straight sided plastic buckets were buried at 5 m intervals with their opening at or slightly below ground level. Two buckets were placed 5 m either side of the centre bucket to form the cross-transect. Where soil conditions—usually the presence of rock at depth—prevented digging the required depth for a 20 L bucket, a 10 L bucket was inserted. This was the case in a few instances only. A low, temporary fence (drift net) of black fly wire 20 cm high was erected along the length of the pitfall line such that it passed over each bucket. To provide captured animals with protection, cardboard cylinders, newspaper, shredded paper and rocks were placed in each bucket. To prevent dehydration, a small amount of water was added to each bucket.
- Elliott traps made up the second part of the 'short arms' of the cross-transect, and continued in both directions from the centre of the pitfall transect. Twelve traps were placed along one length of the cross-transect, and 13 traps on the other. Traps were set at an interval of approximately 15 m. Every effort was made to leave traps in an area that was shaded from direct sun and protected from exposure to adverse weather conditions. As a consequence of this policy no animals died in traps.

In addition, every effort was made to place traplines away from meat ant colonies. These species are pugnacious and their continual biting will stress or kill a small to medium animal in an Elliott or pitfall trap. Note: TS 2 at Site 45a is adjacent to a meat ant colony. The upper walls of each bucket in this site were sprayed with an insecticidal surface spray containing permethrin.

Captured vertebrates were identified, photographed, sexed, released at the point of capture and the data entered into a daily log in the field notes. A small number of animals were collected and subsequently lodged with the SA Museum as per the requirements of the SA DEH permit.

Following the completion of trapping, all Elliott traps were collected, removed from the field and thoroughly washed, rinsed and dried. Routine maintenance, including adjustment of all trap trigger mechanisms to react to a minimum weight was undertaken. Oiling was with fish oil. Pitfall traps were filled with rocks, closed by a secure plastic lid, capped with a large rock, buried with soil and each lid further covered with cobbles and boulders. The centre point of each trapline site was pegged using a 1 m hard wood stake and pink flagging tape.

Spotlighting

Ground-dwelling animals, including small and large mammals, birds, reptiles and amphibians, were surveyed by 12 V spotlights using Coleman spotlights with 50 W and 55 W quartz halogen globes, and Nightforce (Lightforce) spotlights with a 100 W xenophot globe.

As an aid to enhancing the eye-shine of animals and to allow for prolonged observation of animals without causing them alarm or threat, red plastic clip-on filters were used on spotlights during some of the surveys.

Spotlighting surveys were designed to sample all habitats at each site and access tracks under a range of night conditions. Seasonal variation in the abundance and distribution of species and animals was taken into account as far as practicable, but it must be noted that surveys were only undertaken during August and October.

Surveys were based on existing roads and tracks and off-road areas using different techniques as follows:

- Vehicle-based counts used two observers each with a spotlight in a vehicle travelling at a constant speed of between 2–5 km/h. This technique was invaluable in detecting ground-dwelling animals, especially birds, adjacent to access roads and tracks and in the low shrubland vegetation communities.
- Surveys by observers on foot of similar or the same areas to those undertaken above. This technique was used to assess the reliability of vehicle-based surveys, i.e. the survey was less intrusive and noisy and was primarily used to review the reptile diversity, especially the abundance of geckos and the presence of some bird species.
- Surveys by observers on foot over a range of transects such as:
  - straight-line transects along a previously determined course
  - random walk patterns for a set time interval.

In all cases, weather conditions, vehicle or foot travel distances, search time and the number and identity of animals were recorded.

All observers used in spotlighting were experienced in the routine of this technique and the identification of animals using spotlight surveys.

The total effort expended on spotlighting was:

- vehicle—241 km, 97 hours
- on foot—38 km, 43 hours.

Scats and Pellets

Scats, samples of faecal material from omnivores and more especially predator carnivores, were collected. Regurgitated raptor pellets were also collected.

The scats of greatest interest were those from cats and foxes. Owl pellets were recovered from two of the sites. Herbivore scats from small mammals were observed in the field, but not collected.

Hairs, bones, feathers, scales and invertebrate remains are commonly found in scats and pellets. Identification of the prey species is usually possible from these remains. Scats were assessed in the field, their contents reviewed for animal remains and actual/probable prey species recorded in field notes.

Scats were air dried and placed in paper towel until fieldwork was completed. They were then placed on aluminium foil and heated to 250°C for 5 minutes, then held at 200°C for 30 minutes to minimise the risk of parasite or disease transfer to laboratory workers.

Scat and pellet analysis was undertaken by Bob Anderson.

Observation and Active Searching

Direct observations of actual and potential burrows, den and nest sites, diggings/ scratching/forage areas, paw prints and scats were important indicators of the presence of animals.

Prints provided clear evidence of species that had not been directly observed or trapped during the survey (e.g. they are rare or are naturally trap-shy). Based on this evidence, traps could be baited with a target-specific bait or the area identified as an area for a more intensive and focused trapping attention.

Active searching involved rock-turning and in some cases excavating fresh burrows.

Other Evidence Including Anecdotal Information

Observations made about regional fauna by landholders and other biological survey groups were valuable sources of information.

Observations had been made by Defence staff, Dr John Read and pastoralists of particular areas of land, habitat types, and isolated sources of fresh water. These were important clues to areas of significance to animals. Their direct observations of particular animal species, including precise locations were often extremely accurate.

In addition, public roads close to the sites yielded information on the species of road kills in the area. Road kill observations resulted in a recording of two species reported to inhabit the area, but which had not otherwise been observed during the survey.

D2.3.2 Bats

Since flying and foraging activity by bats is negligible during cold weather, spring and early summer surveys (during the times of greatest bat activity, including the mating season) are preferable i.e. in this case, during October 2001. Few species have echolocation calls within the human hearing range, and consequently aural identification of bat calls led to the identification of only one bat species during the surveys. However, ultrasonic detection using the ANABAT call detection system was more successful. Harp traps and mist nets were also used to collect animals for call authentication and species identification.

D2.3.3 Birds

Historical information on bird species for the region was obtained from a range of sources (e.g. Birds Australia and SA Museum databases, and from the Biological Survey of South Australia databases). Information provided by the Biodiversity Unit of Environment Australia, Dr John Read, ornithological groups and field naturalists in the region were also important in understanding the migratory movement of terrestrial and waterbird species, especially migratory wading bird species.

Incidental and programmed observations were made by the field survey team within the region during all fauna assessment periods. These observations were of importance in identifying species or evidence of species of particular conservation significance, including nocturnal species, and habitats of major ecological and conservation significance.

Observation

Systematic observation (primarily visual and aural) surveys of birds were undertaken by the following methods:

- walking a transect across the site
- observation at systematically selected sites in particular areas
- observation at non-randomly chosen sites, primarily adjacent to fauna trapping sites
- incidental observations during other field work activities.

Whenever and wherever practicable, observations were timed to coincide with times of maximum bird activity, at dawn and to about two hours after dawn and two hours prior to sunset for terrestrial species. Additionally, specific attention was focused on areas containing seasonally abundant food or other specific resources, such as remnant water pools in October. During October most bird species were breeding, with chicks or, more rarely, eggs present.

Spotlighting and Other Observation Methods

Nocturnal bird species, such as owls and nightjars, were targeted during spotlight surveys.

Incidental observations were made of owl and raptor pellets, potential nest sites, the remains of birds in predator scats, and road kills in the district.

D2.3.4 Reptiles and Amphibians

Reptiles and amphibians were primarily surveyed using pitfall traps, as described for mammals. Active searching in areas, particularly adjacent to trapping sites was undertaken. Animals trapped and located during active searching were captured and identified. A small number of representative species was subsequently lodged with the SA Museum, whilst the majority were released near their capture site.

D2.3.5 Invertebrates

Invertebrate species were sampled using three techniques:

- collecting species via pitfall traps, including 5 L buckets baited with mammal bait
- captured while actively searching
- captured opportunistically.

All invertebrates captured were placed in a glass jar, labelled with the collection site details, and preserved in 70% ethanol : 30% water. Mr A McArthur and Mr D Hirst of the South Australian Museum undertook identification of ants and spiders respectively.

D2.3.6 Species Lists

Prior to going into the field, species lists of previously recorded vertebrate species were compiled for the region, Arcoona Tableland and project area. These lists provided the predictive model for the field assessment (see Attachments A, B and C).

D2.3.7 Sampling for Radiological Analyses

Samples of flora and fauna were collected during 9–13 October, 2001 using methods recommended by ANSTO and Australian Radiation Protection and Nuclear Safety Agency ARPANSA (pers. comm.). Samples of animal tissue included liver, kidney and edible muscle for vertebrates from Site 40a (sheep and European rabbit) and Site 52a (European rabbit). Whole animal samples were collected for meat ants (*Iridomyrmex*) from all three sites. All samples were collected and stored in heavy gauge, snap-seal plastic bags. Collection data were included on and in each bag.

Following collection, all samples were frozen, packed in dry ice and transported to the relevant laboratory. The Chain of Custody record indicates that all samples were still frozen and in good condition on arrival at the laboratory.

D2.4 Taxonomy and Significance Status

The nomenclature sources applicable to the taxonomy and significance status for each group of fauna is provided in Table D2.2.

TABLE D2.2 Taxonomy and significance status criteria

	Taxonomy		Significance status criteria		
Taxa	**Primary source**	**Other sources**	**Aust**	**SA**	**Regional**
Mammals	Robinson et al. (2000)	NP & WMA Act 2000 Schedules 7, 8 and 9	EPBC Act 1999	2000 Schedules 7, 8 and 9 of the NP & WMA Act 2000	Brandle (1998) Dr J Read, pers. comm. (2001); T Reardon, pers. comm. (2001)
Birds	Robinson et al. (2000)	NP & WMA Act 2000 Schedules 7, 8 and 9	EPBC Act 1999 Garnett and Crowley (2000)	2000 Schedules 7, 8 and 9 of the NP & WMA Act 2000 Garnett & Crowley (2000)	Carpenter and Reid (1998) unpublished database
Reptiles	Robinson et al. (2000)	M. Hutchinson 2001 pers. comm. (where applicable); NP & WMA Act 2000 Schedules 7, 8 and 9	EPBC Act 1999	2000 Schedules 7, 8 and 9 of the NP & WMA Act 2000	Brandle (1998) and pers. comm. (2001); Dr J Read, pers. comm. (2001)
Amphibians	Robinson et al. (2000)	M. Hutchinson 2001 pers. comm. (where applicable); NP & WMA Act 2000 Schedules 7, 8 and 9	EPBC Act 1999	2000 Schedules 7, 8 and 9 of the NP & WMA Act 2000	Brandle (1998) and pers. comm. (2001); Dr J Read, pers. comm. (2001)
Invertebrates	SA Museum (various curators)		n.a.	n.a.	SA Museum (various)

D2.5 Significance Criteria and Assessment

The significance criteria of local, regional, state and national significance are used here. The criteria applied during this study are considered for species (taxon, taxa), site and habitat.

D2.5.1 Species Significance Criteria

Taxa are the categories into which plants and animals are classified (e.g. family, species or subspecies) or specific examples of these categories.

The following criteria have been applied to determine the significance of faunal species:

- Local: All indigenous fauna are significant at a local level, because of the general overall decline in this component of habitat and fauna since European settlement.
- Regional: A taxon is considered significant at a regional level if it has a disjunctive distribution, an unusual ecological occurrence, extraordinary concentration such as colonial nesting, roosting or feeding sites, or if it is substantially depleted or restricted in the region.
- State: A taxon is considered significant at a State level if it is listed as vulnerable, rare or insufficiently known in South Australia (Department of Environment and Natural Resources 1993), or if it is listed under Schedules 7–9 of the *National Parks and Wildlife (Miscellaneous) Amendment Act 2000* (SA) (NP&WMA Act).

- National: A taxon is considered significant at a national level if it is listed under Schedule 1 of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), for example, endangered or vulnerable species or migratory species. Species protected by international agreements (e.g. migratory birds under CAMBA or JAMBA) are of national significance. Note: the Act also protects the habitat of these species. Nationally significant taxa that are endemic to Australia are of international significance (and listed by the International Union for the Conservation of Nature and Natural Resources (IUCN)), although this distinction is rarely made and is not made in this current assessment and report.

The IUCN definitions for ‘extinct’, ‘critical’, ‘endangered’, ‘vulnerable’, ‘rare’ and ‘insufficiently known’ have been used throughout this report (IUCN 1996; Robinson et al. 2000).

Definitions of these terms are provided below:

- Extinct: Taxa not definitely located in the wild during the past 50 years.
- Endangered: Taxa in danger of extinction and whose survival is unlikely if the causal factors continue operating. Included are taxa whose numbers have been reduced to a critical level or whose habitats have been so drastically reduced that they are deemed to be in immediate danger of extinction. Also included are taxa that may be extinct but have definitely been seen in the wild in the past 50 years.
- Vulnerable: Species believed likely to move into the endangered category in the near future if the casual factors continue operating. Included are taxa of which most or all of the populations are decreasing because of over-exploitation, extensive destruction of habitat or other environmental disturbance; species with populations that have been seriously depleted and whose ultimate security has not yet been assured; and taxa with populations that are still abundant but are under threat from severe adverse factors throughout their range.
- Rare: Taxa with small populations that are not at present endangered or vulnerable, but are at risk. These taxa are usually localised within restricted geographical areas or habitats or are thinly scattered over a more extensive range.
- Indeterminate: Taxa known to be endangered, vulnerable or rare, but where there is not enough information to indicate which of the three categories is appropriate.
- Insufficiently known: Taxa that are suspected but not definitely known to belong to any of the above categories. In general this is because of lack of information (‘unknown’ is also applied as an equivalent, alternative category).
- Threatened: This general term is used to denote species which are endangered, vulnerable, rare, indeterminate or insufficiently known.

D2.5.2 Site Significance Criteria

The criteria for determining the zoological significance of sites are considered under local, regional, state and national criteria.

Local Significance

A site is designated as being of local significance if it:

- supports a small population of a regionally rare or unusual species
- supports a population of at least moderate density of a locally depleted species
- has moderate to high potential for serving as a habitat link between two sites of regional significance or as a link to suburban areas to enable native species to disperse into such areas
- has moderate potential for rehabilitation and management for the public appreciation of faunal values.

In effect, all native fauna species are considered to be of some local conservation significance. However, local conservation significance is used here to indicate that a species or habitat is of particular interest in the context of the local area.

Regional Significance

A site is designated as being of regional significance if it:

- supports taxa that are uncommon, restricted and/or have declined in the region
- contains a disjunctive population, an unusual ecological occurrence, extraordinary concentration in a regional context or a naturally restricted (e.g. colonial nesting, roosting or feeding) or substantially depleted or restricted taxon in the region
- supports a high level of species richness in the region
- contains a partial habitat link between two sites of state faunal significance, or a regional and state site, or a primary habitat link between two sites of regional significance, or between a site of state significance and large urban areas
- has a high potential for rehabilitation and management for public appreciation of faunal values.

State Significance

A site is designated as being of state significance if it:

- contains a population of a taxon listed under Schedules 7, 8 and 9 the NP&WMA Act 2000 (SA)
- supports 5% or more of the South Australian population, or an extraordinary concentration in a state context of a native mammal, frog, reptile or fish taxa
- contains an intact primary habitat link containing comparable habitat attributes to two connecting sites or series of sites of state of higher faunal significance
- has high scientific significance (e.g. forms a study site for a particular species or assemblage of species or has particularly biogeographical significance in the region).

National Significance

A site is designated as being of national significance if it:

- contains a population of a taxon listed under Schedule 1 of the EPBC Act
- has had more than 200 species of native birds recorded there since 1970
- contains large concentrations or one or more species covered by international treaties such as Bonn, JAMBA and CAMBA
- supports an appreciable number of rare, vulnerable or endangered taxa
- is of special value for maintaining genetic and ecological diversity of a region because of the quality or peculiarities of its fauna
- is of special value as animal habitat at a critical stage of their biological cycle
- is of special value for its endemic animal species or communities.

D2.5.3 Habitat Significance Criteria

The evaluation of habitat value does not have any rigid guidelines, although a number of criteria can be used. A habitat can have high or particular habitat value for any or all of the following reasons:

- It is a representative or remnant community.
- It constitutes an important wildlife corridor.
- It contains important breeding sites and/or is critical for the survival of a particular species.
- It has unusual ecology or community structure.
- It has high species richness.

Each of these factors is considered within the international, state, regional and local contexts as defined for the species assessments.

Habitat assessment was undertaken for terrestrial vertebrate fauna. The methods used are outlined below.

A habitat is generally formed by floristic and structural features of the vegetation which provide a set of resources to support a community of fauna species. In general, habitat types correspond to vegetation communities; however, habitats may also be defined by other physical attributes of the landscape. Many fauna species move between habitats or use more than one habitat.

Habitat quality was assessed using the following descriptive criteria:

- High: Ground flora contains a relatively large number of indigenous species and nil or few introduced species (weeds) and a relatively complex vegetation community structure; a range and large area of gilgai and cracking soils areas, ground rock and/or litter layer present, intact and undisturbed; an abundance of breeding, nesting and feeding resources available; high richness and diversity of native fauna species.
- Moderate: Ground flora contains a moderate number of indigenous species—vegetation community structure, ground rock and/or litter layer moderately intact and undisturbed; moderate level of breeding, nesting, feeding and roosting resources available; moderate richness and diversity of native fauna species.
- Low: Ground flora contains a small number of indigenous species—vegetation community structure, few or nil areas of gilgai/cracking soils, ground rock and/or litter layer not present, disturbed and modified; low level of breeding, nesting, feeding and roosting resources available; low richness and diversity of native fauna species.

D2.5.4 Other EPBC Act Criteria; Key Threatening Processes

Eleven key threatening processes which may directly and indirectly affect a range of plant and animal species and ecological communities listed under Schedule 3 of the EPBC Act. Of these, four are unlikely to be relevant to the current proposal. The remainder include:

- predation by the European red fox (*Vulpes vulpes*)
- die-back caused by the root-rot cinnamon fungus (*Phytophthora cinnamomi*)
- predation by feral cats
- competition and land degradation by European rabbits (*Oryctolagus Cuniculus)*
- competition and land degradation by feral goats *(Capra hircus)*
- land clearance
- loss of climatic habitat caused by anthropogenic emissions of greenhouse gases.

A number of these factors are present in the region and project area. A relatively small fox population is present. While rabbits are present in low numbers, the local and regional population of this species has increased noticeably in the last 12 months; and feral cats have been found and removed on a regular basis from the region. (Only one cat was recorded, at Site 45a, during the time of survey.)

The potential for die-back caused by *Phytophthora cinnamomi* is probably low. While conditions may be favourable for its spread and development, there are no known local or regional sources of infection.

D2.6 Results

Sites 40a, 45a, and 52a are typical of much of the Arcoona Tableland and essentially comprise three major habitat types:

- canegrass swamp (*Eragrostis australasica*) on cracking soils
- low very open chenopod shrubland or bare ground on gilgai-cracking soils
- low open chenopod shrubland on gibber.

The fixed trapping sites that were established at each potential repository site sampled a similar combination of these habitats, and therefore allowed replication between assessment sites. Figures D2.3, D2.4 and D2.5 illustrate each trapping site. Table D2.3 provides a summary of data for the soils at each site.

TABLE D2.3 Soil data for trapping sites

Site	Comment	Field colour	Texture	Settling behaviour	pH (1:5)	EC_5 (μS)
40a TS1	Large gilgai	Red brown	95% sand/ 5% clay	Remains milky	8.0	3
40a TS1	Gilgai in deeper area, (includes subsoil)	Red brown	95% sand/ 5% clay	Remains milky	8.5	4
40a TS2	Canegrass	Pale red–orange	45% sand/ 55% clay, silt	Settles completely	8.4	44
40a TS3	Large rocky gilgai	Red brown	85% sand/15% clay	Settles completely	8.3	2
45a TS1	Gilgai topsoil	Brown	80% sand/ 20% clay	Generally settles	7.5	21
45a TS1	Gilgai subsoil	Powdery and white (gypsum) Wet–pale brown	30% coarse sand/ 65% fine sand / 5% silt clay	Settles completely	7.5	24
45a TS2	Edge of canegrass	Red brown	50% fine sand/ 50% clay and silt	Settles completely	7.3	44
45a TS3	Gibber/gilgai edge	Dark orange–brown	30% sand/ 70% clay	Generally clears	8.1	9
52a TS1	Canegrass	Milky–pale fawn	5% fine sand/ 95% clay silt	Does not settle	7.4	1
52a TS1	Gibber	Red brown	10% fine sand/ 90% clay silt	Does not settle	7.6	33
52a TS2	Gibber	Deep red	70% sand/ 30% clay	Generally settles	7.5	54
52a TS2	Gibber	Red–brown with orange tinge	15% sand/ 85% clay	Settles	7.6	17
52a TS3	Silcrete gibber	Deep red–brown	15–20% sand/ 80–85% clay	Settles, but clay–silt remains suspended	7.4	41
52a TS3	Edge of small gilgai	Pale red–orange	55% sand/ 45% clay	Settles completely	7.6	38

A total of 2878 trap-nights, comprising 930 pitfall trap-nights and 1948 Elliott trap-nights, were undertaken during the two field surveys. Table D2.4 summarises the trap-nights for each of the sites. Bat survey effort at and around the sites comprised 15 mist-net nights (five nights at each site), 18 harp-trap nights (5 nights at Sites 40a and 52a, and 8 nights at 45a), and 13 ANABAT recording nights (6, 5, and 2 at Sites 40a, 45a and 52a respectively).

TABLE D2.4 Summary of trap-nights

	Site 40a			Site 45a			Site 52a		
Trap-nights	TS1	TS2	TS3	TS1	TS2	TS3	TS1	TS2	TS3
Elliott trap-nights	175	320	225	175	155	175	250	250	220
Pitfall trap-nights	98	52	84	115	118	88	126	126	126
Total trap-nights	273	372	309	290	273	263	376	376	346

TS = trapping site

The weather during the initial survey period was mild, with cool to cold nights and a trace of rainfall. The highest daily maximum was recorded on 10 August, however, 11 and 12 August recorded the highest overnight minimum (10°C).

The October survey provided warmer and slightly wetter weather, with the daily maximum, on average, 3°C above daily maxima for August. Minimum temperatures were not significantly different from those of August, although one night recorded a minimum of 14.7°C. Rainfall was recorded on three days in October, compared to one for the August survey. Rainfall recorded at the Woomera recording station of the Bureau of Meteorology for 10 and 11 October was probably less then that received at Sites 45a and 40a. 'Unofficial' rain gauges recorded 15 mm and 13 mm respectively at Andamooka Homestead and Arcoona Homestead.

Table D2.5 details the daily maximum and minimum temperature and rainfall data during the field survey periods.

TABLE D2.5 Weather conditions during field survey

Trapping night	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall
Wed. 8 August	17.0	4.0	0
Thurs. 9 August	21.0	7.0	0
Fri. 10 August	24.0	9.0	0
Sat. 11 August	21.0	10.0	trace
Sun. 12 August	19.0	10.0	0
Fri. 5 October	27.4	7.9	0
Sat. 6 October	19.7	7.4	0
Sun. 7 October	18.6	7.0	trace
Mon. 8 October	21.3	8.0	0
Tues. 9 October	25.5	9.5	0
Wed. 10 October	25.5	14.7	0.6 mm
Thurs. 11 October	20.8	7.6	2.8 mm
Fri. 12 October	26.2	7.4	0
Sat. 13 October	21.6	13.0	6.0 mm

D2.6.1 Mammals

Trapping and observations at Sites 40a and 45a recorded *Macropus rufus* (red kangaroo), *Macropus fuliginosus* (western grey kangaroo), *Sminthopsis macroura* (striped-faced dunnart), *Planigale tenuirostris* (narrow-nosed planigale) and *Leggadina forresti* (Forrest's mouse). *Canis lupus dingo* (dingo) was present at 45a and fresh tracks were observed at 40a; fresh *Tachyglossus aculeatus* (echidna) scratchings were noted at 40a only. *Pseudomys australis* (plains rat) was only trapped during the October survey, principally at 40a (6 captures), but also at 45a (one trap capture and one animal regurgitated by a captured mulga snake).

No small mammals were observed or captured at Site 52a during the August survey, but *Macropus rufus* (red kangaroo) and *Macropus fuliginosus* (western grey kangaroo) were present. One *Sminthopsis crassicaudata* (fat-tail dunnart) and seven striped-faced dunnart were trapped in October. Table D2.6 summarises the small mammal captures for the three sites from both periods of field work.

Four species of small mammal were captured in pitfall traps, and three in Elliott traps. Forrest's mouse and stripe-faced dunnart were the only species to be trapped using both techniques (see Table D2.13). All specimens were captured on, or from gibber areas adjacent to, deep cracking, gilgai soil.

TABLE D2.6 Small mammal captures[1]

Species	Site 40a	Site 45a	Site 52a
Leggadina forresti	0	8	0
Planigale tenuirostris	6	1	0
Pseudomys australis	6	2	0
Sminthopsis crassicaudata	1	0	1
Sminthopsis macroura	3	14	7
Total	**16**	**25**	**8**

(1) Excludes recaptured animals

No breeding females of any species were observed in August, however five species of small ground mammals and two species of bats were recorded with young in the October survey (Table D2.7). Most *Sminthopsis macroura* females captured during the October survey were breeding. Variation in the development of young was evident: one individual was close to giving birth and others had 3 to 6 young approximately 10 to 25 days old.

TABLE D2.7 Sex[1] and breeding status[2] for all species and sites

Species	Breeding female	Not breeding female	Male
Planigale tenuirostris	2	1	4
Leggadina forresti	3	1	4
Pseudomys australis	5	1	2
Sminthopsis crassicaudata	2	0	0
Sminthopsis macroura	15	2	7

(1) A regurgitated *L. forresti* and the hindquarters of a *P. australis* were from a mulga snake trapped in an Elliott trap.
(2) No species were breeding at the time of the August survey.

Western grey kangaroo and red kangaroo were observed at all sites. Site 40a appears to contain the greatest number of these species. Euros were recorded in the vicinity of Site 52a, near Lake Koolymilka.

The results of the bat survey confirmed that the gibber plains support a depauperate bat assemblage. Table D2.8 summarises the field results.

The results indicate a low abundance and diversity of species across the gibber plains and the region. Generally, relatively high number of calls of *Mormopterus* sp. and *Tadarida australis* were recorded only at some dam sites (e.g. Ram Dam and Marsella Dam near Site 40a). However, analysis of the call data suggests that only a small number of individuals were recorded. In contrast, only two individuals were recorded at the dam immediately north of Site 52a.

TABLE D2.8 Number of recorded bat calls and trapped individuals (in brackets)

Species	Site 40a	Site 45a	Site 52a
Mormopterus sp.	58	0	1
Nyctophilus geoffroyi	4 (5)	13	3
Tadarida australis	110 (1)	3	8
Vespadelus baverstocki	10	0	0
Total number of species	**4**	**2**	**3**

Oryctolagus cuniculus (European rabbit) numbers were low throughout all of the tableland. It was present in small numbers at Site 52a and near Site 40a. *Vulpes vulpes* (red fox) scats (fresh and old) were collected from Sites 40a and 52a, and fresh and old owl pellets were collected from all sites. One adult red fox was observed during spotlighting at Site 52a and cat scats were present at Site 45a.

D2.6.2 Birds

Forty-two bird species were recorded during the field survey across all sites. Table D2.9 identifies the birds observed at each site, with most species residents or opportunists of the Arcoona Tableland. Four seasonal–vagrant species were observed: *Falco peregrinus* (peregrine falcon), *Apus pacificus* (fork-tailed swift), *Petroica goodenovii* (red-capped robin) and *Elseyornis melanops* (black-fronted dotterel).

Not all observations were made within the strict boundaries of the sites; observations from nearby areas were included. (In some instances these records were made outside of gibber habitat.)

Fourteen species of birds were observed to be breeding during October.

D2.6.3 Reptiles and Aphibians

A summary of the reptiles and amphibians captured by pitfall traps, Elliott traps and active searching is provided in Table D2.10.

Sand goanna, sleepy lizard and *Egernia stokesii* (gidgee skink) were also recorded at Phillip Ponds Homestead.

D2.6.4 Invertebrates

Ant specimens were identified by the South Australian Museum to generic level. Specific identification was completed for only *Camponotus ebinithora* and *Iridomyrmex purpureus.* Nine genera were collected across the three sites. Table D2.11 summarises the diversity of genera, functional group representation (as per Andersen 1990) and total abundance score.

Generic diversity was greatest at Site 52a, with eight of the nine genera represented. Actual site richness can only by determined with identification to species level, as genus-richness is not a reliable indicator of species richness (Andersen 1995). Site 52a yielded eight genera, whilst Sites 45a and 40a recorded six and five genera respectively.

Thirty-one spider species, representing 13 families were identified across the three sites. Many specimens were unable to be identified to species level due to the taxonomic difficulties and lack of knowledge at specific level. The most relatively abundant family was Miturgidae (lined spiders), followed by Lycosidae (wolf spiders).

Table D2.12 indicates that Site 52a has a greater spider diversity, and Sites 40a and 45a have lower but similar levels of taxa richness.

6.4.1 Trapping Techniques Review

Table D2.13 provides a comparison of captures according to technique. Pitfall trapping in combination with Elliott traps provided a more comprehensive inventory of small mammals. Reptile trapping required a combination of pitfall traps, active searching and observation.

Pitfall trapping, in comparison to the other survey methods used, was the most successful method for capture of invertebrates.

TABLE D2.9 Bird species list for project area

Species	Common name	Site 40a	Site 45a	Site 52a
Acanthiza apicalis	Inland thornbill			✓
Acanthiza chrysorrhoa	Yellow-rumped thornbill			✓
Acanthiza pusilla	Brown thornbill			✓
Acanthiza uropygialis	Chestnut-rumped thornbill	✓		
Anthus novaeseelandiae	Richard's pipit (B)	✓	✓	✓
Apus pacificus	Fork-tailed swift			✓
Aquila audax	Wedge-tailed eagle	✓	✓	
Ardeotis australis	Australian bustard	✓	✓	✓
Artamus cinereus	Black-faced woodswallow		✓	
Cacatua roseicapilla	Galah	✓		✓
Calamanthus campestris	Rufous fieldwren (B)	✓	✓	✓
Charadrius australis	Inland dotterel (B)	✓	✓	✓
Charadrius ruficapillus	Red-capped plover			✓
Cincloramphus cruralis	Brown songlark (B)	✓	✓	✓
Cinclosoma cinnamomeum	Cinnamon quail-thrush (B)	✓	✓	✓
Coracina novaehollandiae	Black-faced cuckoo-shrike			✓
Corvus coronoides	Australian raven	✓	✓	✓
Coturnix pectoralis	Stubble quail (B)	✓	✓	✓
Dromaius novaehollandiae	Emu (B)	✓	✓	✓
Elanus axillaris	Black-shouldered kite		✓	✓
Elseyornis melanops	Black-fronted dotterel (B)			✓
Epthianura albifrons	White-fronted chat			✓
Epthianura aurifrons	Orange chat (B)	✓	✓	✓
Epthianura tricolor	Crimson chat (B)		✓	
Eurostopodus argus	Spotted nightjar			✓
Falco berigora	Brown falcon		✓	✓
Falco cenchroides	Australian kestrel (B)			✓
Falco peregrinus	Peregrine falcon		✓	
Gallinula ventralis	Black-tailed native hen	✓	✓	✓
Gymnorhina tibicen	Australian magpie	✓		✓
Hirundo neoxena	Welcome swallow	✓	✓	✓
Larus novaehollandiae	Silver gull	✓		✓
Malurus leucopterus	White-winged fairy-wren (B)	✓	✓	✓
Melopsittacus undulatus	Budgerigar		✓	
Merops ornatus	Rainbow bee-eater	✓	✓	
Microeca fascinans	Jacky winter(1)			✓
Ocyphaps lophotes	Crested pigeon		✓	✓
Petroica goodenovii	Red-capped robin		✓	
Pomatostomus superciliosus	White-browed babbler(1)	✓	✓	
Rhipidura fuliginosa	Grey fantail		✓	
Taeniopygia guttata	Zebra finch		✓	✓
Turnix velox	Little button-quail (B)			✓
Vanellus tricolor	Banded lapwing (B)	✓	✓	✓
Total		**21**	**27**	**33**

(1) Adjacent to site
(B) Breeding

TABLE D2.10 Reptile and amphibian species list[(1)]

Species	Common name	Site 40a	Site 45a	Site 52a
Pogona vitticeps	Central bearded dragon	✓	✓	✓
Tympanocryptis lineata	Five-lined earless dragon			✓
Tympanocryptis tetraporophora	Eyrean earless dragon	✓	✓	✓
Diplodactylus damaeus	Beaded gecko	✓		
Diplodactylus tessellatus	Tessellated gecko	✓		✓
Heteronotia binoei	Bynoe's gecko	✓	✓	
Nephrurus milii	Barking gecko		✓	✓
Ctenotus olympicus	Saltbush ctenotus		✓	✓
Ctenotus schomburgkii	Sandplain ctenotus			✓
Ctenotus strauchii	Short-legged ctenotus	✓	✓	
Lerista dorsalis (Red tail)	Southern four-toed slider	✓	✓	✓
Menetia greyii	Dwarf skink		✓	✓
Morethia adelaidensis	Common snake-eye	✓		
Tiliqua rugosa	Sleepy lizard	✓	✓	
Varanus gouldii	Sand goanna		✓	
Pseudechis australis	Mulga snake		✓	
Pseudonaja nuchalis	Western brown snake	✓		✓
Suta suta	Curl snake			✓
Neobatrachus centralis	Trilling frog	✓	✓	✓
Total		**11**	**12**	**12**

(1) Taxonomic order as per Robinson et al. 2000.

TABLE D2.11 Ant collections

Functional group	Genus	Common name	Total abundance score		
			Site 40a	Site 45a	Site 52a
Dominant Dolichoderinae	*Iridomyrmex* spp.	Meat ants	8	12	13
Associated subordinate Camponotinae	*Camponotus* spp.	Sugar ants	3	4	4
Hot climate specialists	*Melophorus* spp.	Honey pot ants	1	3	2
Cold climate specialists	*Prolasius* sp.		0	9	1
Cryptic species	*Hypoponera* spp.		0	0	2
Sub-cryptic species	–		0	0	0
Opportunists	*Rhytidoponera* spp.	Greenhead ants	4	8	8
	Odontomachus spp.		0	0	3
Generalised myrmicines	*Monomorum* spp.		0	6	0
	Pheidole spp.	Seed harvesting ants	3	0	2
Large, solitary and/or specialist predators	–		0	0	0

TABLE D2.12 Spider collections

Family	Common name	Relative abundance score		
		Site 40a	Site 45a	Site 52a
Amaurobiidae	–	**0**	**0**	**1**
Desidae	–	1	2	1
Dictynidae	–	0	0	1
Miturgidae	Lined spiders	2	4	5
Zoridae	–	0	1	2
Corinnidae	–	0	0	2
Oxyopidae	Lynx spiders	0	3	2
Gnaphosidae	Ground spiders	0	2	1
Lamponidae	White-tailed spiders	1	1	1
Zodariidae	Spotted ground spiders	2	2	2
Lycosidae	Wolf spiders	3	4	2
Prodidomidae	–	1	0	2
Nicodamidae	–	3	0	2
Total no. families		**7**	**8**	**13**

D2.7 Discussion

Site 52a had the greatest faunal diversity, with 57 species of vertebrates, 8 genera of ants, and 17 taxa of spiders. The site recorded the highest diversity of birds, reptiles, ants and spiders, but the lowest mammal diversity. Site 45a contained the highest diversity of vertebrates, with 6 mammal, 26 bird, and 11 reptile species. All sites are similar in vertebrate faunal diversity.

Small mammals were recorded at all three sites. Site 52a had the lowest diversity, richness and abundance, with two species, compared to four for both Sites 40a and 45a. The data indicated that there is limited variation in vertebrate faunal richness between habitat. All trapping sites recorded similar species diversity, regardless of soil type or type of vegetation cover.

Gilgai and gilgai/gibber ecotone consistently recorded only one or two small mammal species: at 40a *Pseudomys australis* (plains rat), at 45a *Leggadina forresti* (Forrest's mouse) and *Sminthopsis macroura* (stripe-faced dunnart), and at 52a stripe-faced dunnart only.

The most abundant species captured for all sites was stripe-faced dunnart, with a total of 24 captures. These data accord with the findings of Brandle (1998). This species was recorded in all habitats, with a preference for gilgai/gibber habitat rather than canegrass. In comparison, the least trapped species was fat-tailed dunnart (*S. crassicaudata*), with two captures, both in canegrass.

Gilgai and 'cracking clay' soil is a key habitat, with all small mammal captures within or immediately adjacent to such areas. Both Sites 40a and 45a have much larger areas of gilgai than Site 52a. The low number of small mammals captured on Site 52a (8 individuals compared to 16 and 25 at Sites 40a and 45a respectively) indicates the importance of these soils for small mammals, and accords with the data presented by Owens and Read (1999).

Elliott trapping using lucerne pellets and the standard bait proved the most successful method for rodents and *S. macroura* respectively. *Planigale tenuirostris* was the only species to be consistently trapped in pitfall buckets. In comparison, pitfall trapping in combination with active searching and observation was successful for reptiles. Only one species, *Pseudechis australis*, was not captured using these methods.

TABLE D2.13 Comparison of vertebrate species numbers according to survey method

Scientific name	Survey method[1]									
	PT	ET	HT	MN	BD	AS	OB	S	D/T	SP
Mammals										
Canis lupus dingo							1	2	1	1
Leggadina forresti	1	7								
Macropus fuliginosus							30+	30+		1
Macropus robustus							1			3
Macropus rufus							30+	30+		
Mormopterus sp.					59					
Nyctophilus geoffroyi			6		20					
Planigale tenuirostris	7									
Pseudomys australis		7								
Sminthopsis crassicaudata	1	1								
Sminthopsis macroura	10	14						1		
Tachyglossus aculeatus									1	
Tadarida australis				1	121					
Vespadelus baverstocki					10					
*Oryctolagus cuniculus**								+	3	6
*Vulpes vulpes**								2		1
Amphibians										
Neobatrachus centralis	3					1				
Reptiles										
Pogona vitticeps						2	3			
Tympanocryptis lineata						1				
Tympanocryptis tetraporophora	18	1				4	14			
Diplodactylus damaeus							1			
Diplodactylus tessellatus	2					9				
Heteronotia binoei	1					2				
Nephrurus milii	1					4				
Ctenotus olympicus	9	1				3				
Ctenotus schomburgkii								1		
Ctenotus strauchii	4						2			
Lerista dorsalis (Red tail)	11					1	2			
Menetia greyii	2					1	1			
Morethia adelaidensis	4					1				
Tiliqua rugosa	1	1				1	5			
Varanus gouldii						1	4			
Pseudechis australis		1				1				
Pseudonaja nuchalis							2			
Suta suta	1									
Neobatrachus centralis	2					5			2	3

* Introduced species
(1) Method of capture: PT = pitfall trap; ET = Elliott trap; HT = harp trap; MN = mist net; BD = bat detector; AS = active searching; OB = observation; S = scat; D/T = digging/tracks; SP = spotlighting

The bat diversity and abundance at the three sites is low, and is in accordance with data from previous surveys in the area. The lack of structural diversity and thus roosting sites near the sites, limits the habitat available for bats. The importance of water resources as habitat for species and individuals in the Woomera region is variable, and perhaps linked to the availability of roosting habitat near by. This was highlighted near Site 40a with a large number of calls at Marsella Dam with roosting sites in nearby *Acacia* woodland. Only two calls were recorded at the dam near Site 52a, a site without nearby roosting habitat.

The ground mammal assemblage recorded corresponds closest with Brandle's (1998) mammal group 6. Group 6 includes *Planigale gilesi* (Giles' planigale) and *Rattus villosissimus* (long-haired rat), both which were not captured during the field surveys, and *R. villosissimus* does not occur on the Arcoona Tableland. Assemblage 5 contains a similar diversity to that noted during the field survey, however is characterised by *P. gilesi* at all sites. This species, although predicted to occur, was not recorded.

Bird diversity was greatest at Site 52a, with seven more species than Site 45a and 13 more than Site 40a. Sites 45a and 52a have greater habitat diversity within and immediately surrounding the sites. These sites have relatively large water sources and structurally different–diverse habitats nearby. Dromedary Dam is situated 2 km northeast of the site, and an isolated sand ridge is within 1 km of the northern boundary. Similarly, a dam is located 1 km northwest of Site 52a and 1 km to the southeast is Wild Dog Creek (which flows into Lake Koolymilka) and its associated habitat. Both regions also have some large areas of canegrass within 1 km of the boundary of each site. Not only do these habitats provide an important refuge for resident species, they are probably significant for vagrant and migratory species moving between resources and areas.

The majority of birds recorded across the sites are residents of the Arcoona Tableland or nomadic. Only four species, *Falco peregrinus* (peregrine falcon), *Apus pacificus* (fork-tailed swift), *Petroica goodenovii* (red-capped robin) and *Elseyornis melanops* (black-fronted dotterel) are considered to be of vagrant or seasonal nature.

Brandle's (1998) group 23 best represents the avifauna assemblage recorded for the three sites. The group is defined by *Calamanthus campestris* (western fieldwren) and *Malurus leucopterus* (white-winged wren), with *C. campestris* present at all sites. Group 23 is closely allied to group 22, a group with *M. leucopterus, Anthus novaeseelandiae* (Richard's pipit) and *C. campestris* as dominant indicators. This group is also more diverse in species, with 16 species compared with seven. Groups 9 and 16 represent some of the characteristics of the sites and their avifauna assemblages.

Reptile family and species richness is comparable across all sites. It is probable that the recorded reptile diversity does not reflect the true diversity present, primarily due to the unseasonally cool conditions across southern Australia during October and November. Snakes, skinks, blind snakes, goannas and legless lizards are under-represented across all of the sites (compared to the previously recorded lists in Attachment C).

Brandle's (1998) group 18 strongly resembles the reptile diversity found at the three study sites. *Ctenotus olympicus* (saltbush ctenotus) and *Tympanocryptis tetraporophora* (Eyrean earless dragon) are dominant indicator species of this group, being found at all sites. *Pygopus nigriceps* (black-headed scaly-foot) and *C. septenarius* (gibber ctenotus) are members of this group, but were not recorded during the field survey. *P. nigriceps* is predicted to occur in the region whilst *C. septenarius* is unlikely to occur on the Arcoona Tableland. Brandle's captures of *C. septenarius* were outside of the Arcoona Tableland region. Groups 16 and 17 also include similar reptile assemblages as recorded during the field surveys.

Only one amphibian, *Neobatrachus centralis*, was recorded at all sites. No captures were made during the October survey, even though puddles were present at the sites and all dams had water in them.

Species of conservation significance are summarised in Table D2.14.

TABLE D2.14 Species of conservation significance

Species	Common name	Conservation status		Site recorded
		National(1)	State(2)	
Ardeotis australis	Australian bustard	–	Vulnerable	40a, 45a
Falco peregrinus	Peregrine falcon	–	Rare	45a
Leggadina forresti	Forrest's mouse	–	Rare	45a
Planigale tenuirostris	Narrow-nosed planigale	–	Uncommon	40a, 45a
Pseudomys australis	Plains rat	Vulnerable	Vulnerable	40a, 45a

(1) Commonwealth EPBC Act
(2) South Australian NP&W Act and NP&WMA Act

Ardeotis australis is a nomadic species, whilst *Falco peregrinus* is considered vagrant in the area. Both species are unlikely to be breeding in the area, and future sightings will probably be irregular and infrequent.

Pseudomys australis at Sites 40a and 45a is a significant record for the Arcoona Tableland and the State. Previous studies on the Arcoona Tableland have produced very few records for the species:

- The South Australian Museum has two records approximately 16 km northwest of Woomera (Ashton Hill, towards Lake Koolymilka).
- Brandle et al. (1999) recorded the species for North Tiffen, Pernatty Station west of Lake Torrens (Rare Rodent Survey site).
- Brandle (1998) did not record the species on the Arcoona Tableland.

The records from the current survey are significant, particularly the location and habitat of capture. Excluding the recent record from Ashton Hill, the species has not been recorded in the central area of the Arcoona Tableland for 40+ years. Furthermore, the specimens captured on Site 40a were made in a variety of habitats, but particularly on large areas of rocky gilgai. This habitat was considered by Brandle et al. (1999) to be a secondary habitat. One specimen from Site 45a was a partly digested animal regurgitated by a mulga snake.

Forrest's mouse and narrow-nose planigale are classified in Brandle (1998) and the NP&WMA Act respectively as being rare and uncommon (insufficiently known). The status of Forrest's mouse in Australia is considered to be stable by Lee et al*.* (1995) and Brandle (1998) indicates that the species is common and widespread across the region. The Australian status of this species is also considered as being secure and Brandle (1998) indicates that the species is relatively common and widespread throughout most of the stony deserts of South Australia.

The diversity of ant genera is less uniform than that of vertebrates. Site 52a had a richness of eight genera compared to five genera for the other two sites. Functional group distribution for the three sites is comparable to that expected for low disturbance sites (Andersen 1993). Dominant Dolichoderinae (*Iridomyrmex* spp.) are the most abundant species, proportionally followed by opportunistic species (*Rhytidoponera* spp. and *Odontomachus* spp.). One cold climate species (*Prolasius* sp.) was recorded at Sites 45a and 52a. This group is more abundant in habitat with reduced *Iridomyrmex* (Andersen 1990) and is considered to be an uncommon taxon (Greenslade 1979; A McArthur, SA Museum, pers. comm., November 2001). *Hypoponera* (a cryptic species) was only recorded at Site 52a. No sub-cryptic or solitary foragers were recorded at any site.

These ant survey results are based upon a relatively small temporal survey sample. A more detailed survey during warmer weather would result in enhanced species diversity and abundance.

Data for spiders indicates that Site 52a has the greatest species richness. Both Sites 40a and 45a have a similar but lower diversity of ground dwelling spiders. Lined spiders (Miturgidae) were the most abundant, followed by wolf spiders (Lycosidae). Amaurobiidae and Dictynidae were the least collected, with only one specimen recorded (both at Site 52a). Site 52a was the only site to record at least one specimen for all families represented.

The Amaurobiidae specimen from Site 52a has not previously been collected, and consequently is of particular scientific and taxonomic interest. The collection of *Durodamus yeni* at Sites 40a and 52a considerably extends the known distribution of this species. The most western location was previously from Etadunna Station, 300 km northeast of Woomera.

Although the gibber plains have a low structural vegetation diversity, greater spider richness would be obtained if additional sampling was undertaken. The results are biased towards ground-dwelling spiders as a consequence of the sampling methods. Therefore, the results do not indicate total diversity, but rather relative diversity. More extensive seasonal sampling, and sampling in all habitats will probably provide a greater diversity of taxa.

Invertebrate diversity between habitat types was similar at Sites 40a and 45a. However, the canegrass swamp/gibber ecotone at Site 52a yielded much lower spider diversity in comparison with the gilgai/gibber plain ecotone. The results of this fauna survey indicated that a diversity of vertebrate and invertebrate species typical of the Arcoona Tableland are present at all three sites. The ecotone between canegrass and gibber, and gilgai areas generally, provided the most heavily used and species rich habitat for a number of species. All sites exhibit slight differences in species diversity and abundance and all should be considered as part of the regional context for the tableland, that is they are part of the continuum of habitats across the land system.

Sites 40a and 45a have a population of an internationally and nationally vulnerable rodent, plains rat. Therefore, proposed use of these sites for the repository would require a more stringent review of the actual population and ecology of the region around these sites to accord with the requirements of the EPBC Act.

D2.8 References

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D2.9 Attachment A: Fauna Lists for Region, Arcoona Tableland and Project Area

Mammal Species Recorded in the Region, Arcoona Tableland and Project Area

					Recorded in field survey		
Scientific name	Common name	Status	Regional occurrence[(1)]	Arcoona tableland[(2)]	40a	45a	52a
Tachyglossidae							
Tachyglossus aculeatus	Short-beaked echidna		✓	✓			
Dasyuridae							
Antechinomys laniger	Kultarr		✓	✓			
Planigale gilesi	Giles' planigale		✓	✓			
Planigale tenuirostris	Narrow-nosed planigale		✓	✓	✓		
Sminthopsis crassicaudata	Fat-tailed dunnart		✓	✓			
Sminthopsis macroura	Striped-faced dunnart		✓	✓		✓	
Macropodidae							
Macropus fuliginosus	Western grey kangaroo		✓		✓		
Macropus robustus	Euro		✓	✓			
Macropus rufus	Red kangaroo		✓	✓			
Molossidae							
Mormopterus planiceps	Southern freetail-bat		✓				
Nyctinomus australis	White-striped freetail-bat		✓				
Vespertilionidae							
Chalinolobus gouldii	Gould's wattle bat		+				
Nyctophilus geoffroyi	Lesser long-eared bat		✓				
Nyctophilus timoriensis	Greater long-eared bat	SA V	+				
Saccolaimus flaviventris	Yellow-bellied sheathtail-bat	SA R	+				
Scotorepens balstoni	Inland broad-nosed bat		✓				
Scotorepens greyii	Little broad-nosed boat		✓				
Vespadelus baverstocki	Inland forest bat		✓	✓			
Vespadelus pumilis	Eastern forest bat		✓				

Scientific name	Common name	Status	Regional occurrence[1]	Arcoona tableland[2]	Recorded in field survey		
					40a	45a	52a
Vespadelus vulturnus	Little forest bat		✓				
Muridae							
Leggadina forresti	Forrest’s mouse		✓	✓			
*Mus musculus**	House mouse		✓	✓			
Notomy salex	Spinifex hopping-mouse		✓				
Notomys fuscus	Dusky hopping-mouse	Aus V; SA V	✓				
Pseudomys australis	Plains rat	Aus V; SA V	✓	✓			
Pseudomys bolami	Bolam’s mouse		✓	✓			
Pseudomys desertor	Desert mouse		✓				
Pseudomys hermannsburgensis	Sandy inland mouse			✓			
*Rattus rattus**	Black rat		✓				
Canidae							
Canis familiaris dingo	Dingo		✓				
*Vulpes vulpes**	Fox		✓	✓			
Felidae							
*Felis catus**	Cat		✓				
Leporidae							
*Oryctolagus cuniculus**	European rabbit		✓	✓			
Bovidae							
*Bos taurus**	Cattle			✓			
*Capra hircus**	Feral goat			✓			
*Ovis aries**	Sheep			✓			

(1) Kinhill Engineers Pty Ltd (1997) and SA Museum records
(2) Brandle (1998) and SA Museum records

+ Species potentially occurs in the region
* Introduced species

D2.10 Attachment B: Avifauna of the Region, Arcoona Tableland and Project Area

Scientific name[(1)]	Common name	Status	Regional occurrence[(2)]	Arcoona tableland[(3)]	Habit[(4)]	Recorded in field survey		
						40a	45a	52a
Casuariidae								
Dromaius novaehollandiae	Emu		✓	✓	N/Re			
Phasianidae								
Coturnix pectoralis	Stubble quail		✓	✓	N			
Turnicidae								
Turnix velox	Little button-quail		✓	✓	N			
Pelecanidae								
Pelecanus conspicillatus	Australian pelican		✓	✓	N			
Anhingidae								
Anhinga melanogaster	Darter		✓	✓	N			
Phalacrocoracidae								
Phalacrocorax varius	Pied cormorant		✓	✓	N			
Phalacrocorax melanoleucos	Little pied cormorant		✓	✓	N			
Phalacrocorax carbo	Great cormorant		✓	✓	N			
Phalacrocorax sulcirostris	Little black cormorant		✓	✓	N			
Podicipedidae								
Podiceps cristatus	Great-crested grebe	SA R	✓	✓	N/Va			
Poliocephalus poliocephalus	Hoary-headed grebe		✓	✓	N/Re			
Tachybaptus novaehollandiae	Australasian grebe		✓	✓	N/Re			
Anatidae								
Cygnus atratus	Black swan		✓	✓	N			
Tadorna tadornoides	Australian shelduck		✓	✓	N			
Anas superciliosa	Pacific black duck		✓	✓	N			
Anas gracilis	Grey teal		✓	✓	N			

Scientific name[(1)]	Common name	Status	Regional occurrence[(2)]	Arcoona tableland[(3)]	Habit[(4)]	Recorded in field survey		
						40a	45a	52a
Anas castanea	Chestnut teal		✓	✓	N			
Anas rhynchotis	Australian shoveler	SA R	✓	✓	N			
Malacorhynchus membranaceus	Pink-eared duck		✓	✓	N			
Aythya australis	Hardhead		✓	✓	N			
Chenonetta jubata	Wood duck		✓	✓	N			
Stictonetta naevosa	Freckled duck	SA V	✓	✓	N			
Oxyura australis	Blue-billed duck	SA R	✓	✓	N			
Biziura lobata	Musk duck	SA R	✓	✓	N			
Rallidae								
Gallirallus philippensis	Buff-banded rail		✓		N			
Porzana pusilla	Baillon's crake	SA R	✓		N/Va			
Porzana fluminea	Australian spotted crake		✓		N			
Gallinula ventralis	Black-tailed native-hen		✓	✓	N			
Gallinula tenebrosa	Dusky moorhen		✓		N			
Porphyrio porphyrio	Purple swamphen		✓		N			
Fulica atra	Eurasian coot		✓	✓	N			
Ardeidae								
Ardea pacifica	White-necked heron		✓	✓	N			
Egretta novaehollandiae	White-faced heron		✓	✓	N			
Ardea ibis	Cattle egret		✓		N/Va			
Ardea alba	Great egret		✓	✓	N			
Egretta garzetta	Little egret		✓	✓	N			
Ardea intermedia	Intermediate egret	SA R	✓		N			
Nycticorax caledonicus	Nankeen night heron		✓	✓	N/Va			
Threskiornithidae								
Plegadis falcinellus	Glossy ibis	SA R	✓	✓	N			
Threskiornis molucca	Sacred ibis		✓	✓	N			
Threskiornis spinicollis	Straw-necked ibis		✓	✓	N			
Platalea flavipes	Yellow-billed spoonbill		✓	✓	N			

Scientific name[1]	Common name	Status	Regional occurrence[2]	Arcoona tableland[3]	Habit[4]	Recorded in field survey		
						40a	45a	52a
Gruidae								
Grus rubicunda	Brolga	SA V	✓		Va			
Otididae								
Ardeotis australis	Australian bustard	SA V	✓	✓	N			
Pedionomidae								
Pedionomus torquatus	Plains-wanderer	Aus V; SA E	✓		Va			
Scolopacidae								
Arenaria interpres	Ruddy turnstone		✓	✓	S/Va			
Numenius madagascariensis	Eastern curlew	SA V	✓	✓	S/Va			
Tringa glareola	Wood sandpiper		✓	✓	S			
Actitis hypoleucos	Common sandpiper		✓	✓	S			
Tringa nebularia	Greenshank		✓	✓	S/Re			
Tringa stagnatilis	Marsh sandpiper		✓	✓	S			
Gallinago hardwickii	Latham's snipe	SA V	✓		S/Va			
Limosa limosa	Black-tailed godwit		✓	✓	S/Va			
Calidris acuminata	Sharp-tailed sandpiper		✓	✓	S			
Calidris ruficollis	Red-necked stint		✓	✓	S			
Calidris ferruginea	Curlew sandpiper		✓	✓	S			
Glareolidae								
Glareola maldivarum	Oriental pratincole		✓		S/Va			
Stiltia isabella	Australian pratincole		✓		S/Va			
Charadriidae								
Vanellus miles	Masked lapwing		✓	✓	Re			
Vanellus tricolor	Banded lapwing		✓	✓	N			
Pluvialis squatarola	Grey plover		✓	✓	S/Va			
Erythrogonys cinctus	Red-kneed dotterel		✓	✓	N			
Charadrius ruficapillus	Red-capped plover		✓	✓	N			
Elseyornis melanops	Black-fronted dotterel		✓	✓	S/Re			
Charadrius australis	Inland dotterel		✓	✓	N/S			

Scientific name[1]	Common name	Status	Regional occurrence[2]	Arcoona tableland[3]	Habit[4]	Recorded in field survey		
						40a	45a	52a
Recurvirostridae								
Himantopus himantopus	Black-winged stilt		✓	✓	N/Re			
Cladorhynchus leucocephalus	Banded stilt		✓	✓	N			
Recrvirostra novaehollandiae	Red-necked avocet		✓	✓	N			
Laridae								
Larus novaehollandiae	Silver gull		✓	✓	N/Re			
Chlidonias hybridus	Whiskered tern		✓	✓	N			
Sterna caspia	Caspian tern		✓	✓	N			
Sterna nilotica	Gull-billed tern		✓	✓	N			
Accipitridae								
Elanus axillaris	Black-shouldered kite		✓		N			
Hamirostra melanosternon	Black-breasted buzzard	SA R	✓	✓	N			
Milvus migrans	Black kite		✓	✓	S/Re			
Haliastur sphenurus	Whistling kite		✓	✓	Re			
Aquila audax	Wedge-tailed eagle		✓	✓	Re			
Hieraaetus morphnoides	Little eagle		✓		Re			
Accipiter fasciatus	Brown goshawk		✓		N			
Accipiter cirrhocephalus	Collared sparrowhawk		✓	✓	N			
Circus assimilis	Spotted harrier		✓	✓	N			
Circus approximans	Swamp harrier		✓		N			
Falconidae								
Falco subniger	Black falcon		✓		N			
Falco peregrinus	Peregrine falcon	SA R	✓		Va			
Falco longipennis	Australian hobby		✓	✓	N			
Falco berigora	Brown falcon		✓	✓	Re			
Falco cenchroides	Australian kestrel		✓	✓	Re			
Columbidae								
*Columba livia**	Feral pigeon		✓		N			
Geopelia striata	Peaceful dove		✓		N			
Geopelia cuneata	Diamond dove		✓		N			

Scientific name[1]	Common name	Status	Regional occurrence[2]	Arcoona tableland[3]	Habit[4]	Recorded in field survey		
						40a	45a	52a
Phaps chalcoptera	Common bronzewing		✓	✓	N			
Phaps histrionica	Flock bronzewing	SA V	✓		N/Va			
Ocyphaps lophotes	Crested pigeon		✓	✓	Re			
Cacatuidae								
Cacatua roseicapilla	Galah		✓	✓	Re			
Cacatua sanguinea	Little corella		✓		Re			
Cacatua leadbeateri	Pink cockatoo	SA V	✓		N			
Nymphicus hollandicus	Cockatiel		✓	✓	N			
Psittacidae								
Melopsittacus undulatus	Budgerigar		✓	✓	N			
Psephotus haematonotus	Red-rumped parrot			✓	N			
Psephotus varius	Mulga parrot		✓	✓	N			
Barnardius zonafius	Ring-necked parrot		✓	✓	N			
Northiella haematogaster	Blue bonnet		✓		Re			
Neopsephotus bourkii	Bourke's parrot		✓		Re			
Neophema chrysostoma	Blue-winged parrot	SA V	✓	✓	N/S			
Cuculidae								
Cuculus saturatus	Oriental cuckoo		✓		N/S			
Cuculus pallidus	Pallid cuckoo		✓		N			
Chrysococcyx osculans	Black-eared cuckoo		✓		N			
Chrysococcyx basalis	Horsfield's bronze-cuckoo		✓	✓	N			
Strigidae								
Ninox novaeseelandiae	Southern boobook		✓		N			
Tytonidae								
Tyto alba	Barn owl		✓	✓	N			
Podargidae								
Podargus strigoides	Tawny frogmouth		✓	✓	Re			

Scientific name[(1)]	Common name	Status	Regional occurrence[(2)]	Arcoona tableland[(3)]	Habit[(4)]	Recorded in field survey		
						40a	45a	52a
Aegothelidae								
Aegotheles cristatus	Australian owlet-nightjar		✓		Re			
Caprimulgidae								
Eurostopodus argus	Spotted nightjar		✓		N			
Apodidae								
Apus pacificus	Fork-tailed swift		✓	✓	Va			
Halcyonidae								
Todiramphus pyrrhopygia	Red-backed kingfisher		✓		S			
Todiramphus sanctus	Sacred kingfisher			✓	S			
Meropidae								
Merops ornatus	Rainbow bee-eater		✓		S			
Neosittidae								
Daphoenositta chrysoptera	Varied sittella		✓		N			
Maluridae								
Malurus splendens	Splendid fairy-wren		✓		Re			
Malurus lamberti	Variegated fairy-wren		✓	✓	Re			
Malurus leucopterus	White-winged fairy-wren		✓	✓	Re			
Amytornis textilis myall	Thick-billed grasswren	Aus V; SA R	✓	✓	N			
Pardalotidae								
Pardalotus rubricatus	Red-browed pardalote		✓		N			
Pardalotus striatus	Striated pardalote		✓		N/S			
Calamanthus campestris	Rufous fieldwren		✓	✓	Re			
Calamanthus fuliginosus	Striated fieldwren		✓		Re			
Acanthiza apicalis	Inland thornbill		✓		Re			
Acanthiza iredali	Slender-tailed thornbill	SAV		✓	N			
Acanthiza uropygialis	Chestnut-rumped thornbill		✓	✓	Re			
Acanthiza chrysorrhoa	Yellow-rumped thornbill		✓	✓	N			
Aphelocephala leucopsis	Southern whiteface		✓		Re			

Scientific name[(1)]	Common name	Status	Regional occurrence[(2)]	Arcoona tableland[(3)]	Habit[(4)]	Recorded in field survey		
						40a	45a	52a
Meliphagidae								
Acanthagenys rufogularis	Spiny-cheeked honeyeater		✓	✓	Re			
Manorina flavigula	Yellow-throated miner		✓		Re			
Lichenostomus virescens	Singing honeyeater		✓	✓	Re			
Lichenostomus plumulus	Grey-fronted honeyeater		✓		Va			
Lichenostomus penicillatus	White-plumed honeyeater		✓		Re			
Phylidonyris albifrons	White-fronted honeyeater		✓		N			
Certhionyx variegatus	Pied honeyeater		✓		N			
Epthianura tricolor	Crimson chat		✓	✓	N			
Epthianura aurifrons	Orange chat		✓	✓	N			
Epthianura albifrons	White-fronted chat		✓		N			
Ashbyia lovensis	Gibberbird		✓		N			
Cinclosomatidae								
Psophodes cristatus	Chirruping wedgebill		✓	✓	Re			
Cinclosoma cinnamomeum	Cinnamon quail-thrush		✓	✓	Re			
Pomatostomidae								
Pomatostomus superciliosus	White-browed babbler		✓	✓	Re			
Petroicidae								
Petroica goodenovii	Red-capped robin		✓	✓	S			
Melanodryas cucullata	Hooded robin		✓	✓	Re			
Pachycephalidae								
Oreoica gutturalis	Crested bellbird		✓	✓	Re			
Colluricincla harmonica	Grey shrike-thrush		✓	✓	Re			
Pachycephala rufiventris	Rufous whistler		✓		S/Va			
Dicruridae								
Rhipidura fuliginosa	Grey fantail		✓		N			
Rhipidura leucophrys	Willie wagtail		✓	✓	Re			
Myiagra inquieta	Restless flycatcher		✓		N			
Grallina cyanoleuca	Magpie-lark		✓		Re			

Scientific name[(1)]	Common name	Status	Regional occurrence[(2)]	Arcoona tableland[(3)]	Habit[(4)]	Recorded in field survey		
						40a	45a	52a
Campephagidae								
Coracina novaehollandiae	Black-faced cuckoo-shrike		✓	✓	Re			
Coracina maxima	Ground cuckoo-shrike		✓	✓	N			
Lalage sueurii	White-winged triller		✓		S			
Artamidae								
Artamus lecuorhynchus	White-breasted woodswallow		✓		Re			
Artamus personatus	Masked woodswallow		✓		N			
Artamus superciliosus	White-browed woodswallow		✓		N			
Artamus cinereus	Black-faced woodswallow		✓	✓	Re			
Cracticus torquatus	Grey butcherbird		✓	✓	Re			
Gymnorhina tibicen	Australian magpie		✓	✓	Re			
Corvidae								
Corvus coronoides	Australian raven		✓	✓	Re			
Corvus bennetti	Little crow		✓	✓	Re			
Hirundinidae								
Cheramoeca leucosternus	White-backed swallow		✓		Re			
Hirundo neoxena	Welcome swallow		✓	✓	Re			
Hirundo nigricans	Tree martin		✓		S			
Hirundo ariel	Fairy martin		✓		S			
Motacillidae								
Anthus novaeseelandiae	Richard’s pipit		✓	✓	Re			
Alaudidae								
Mirafra javanica	Singing bushlark			✓	N			
Sylviidae								
Acrocephalus stentoreus	Clamorous reed-warbler		✓		N/Re			
Megalurus gramineus	Little grassbird		✓	✓	N/Re			
Cincloramphus mathewsi	Rufous songlark		✓		N			
Cincloramphus cruralis	Brown songlark		✓	✓	N			

						Recorded in field survey		
Scientific name[(1)]	Common name	Status	Regional occurrence[(2)]	Arcoona tableland[(3)]	Habit[(4)]	40a	45a	52a
Passeridae								
*Passer domesticus**	House sparrow		✓		Re			
Taeniopygia guttata	Zebra finch		✓	✓	Re			
Dicaeidae								
Dicaeum hirundinaceum	Mistletoebird		✓		N/S			
Sturnidae								
*Sturnus vulgaris**	Common starling		✓		N/Re			

(1) Taxonomy after Christidis & Boles (1994)
(2) Kinhill Engineers Pty Ltd (1997) and SA Museum
(3) Brandle R (1998), Read JL and Ebdon FR (1998) SA Museum and J Read (pers. comm. January 2002)
(4) After Kinhill Engineers Pty Ltd (1997)
N = nomadic (long-distance movements); Re = resident (may move small distances locally); S = seasonal visitor; Va = vagrant (outside normal recognised range)
* Introduced species

D2.11 Attachment C: Herpetofauna of the Arcoona Tableland, Project Area and Region

					Recorded in field survey		
Scientific name	**Common name**	**Status**	**Regional occurrence[(1)]**	**Arcoona tableland[(2)]**	**40a**	**45a**	**52a**
REPTILES							
Agamidae							
Ctenophorus fionni	Peninsula dragon		✓	✓			
Ctenophorus fordi	Mallee dragon		✓	✓			
Ctenophorus gibba	Gibber dragon						
Ctenophorus nuchalis	Central netted dragon		✓	✓			
Ctenophorus pictus	Painted dragon		✓	✓			
Pogona vitticeps	Central bearded dragon		✓	✓			
Tympanocryptis intima	Smooth-snouted earless dragon		✓	✓			
Tympanocryptis lineata	Five-lined earless dragon		✓				
Tympanocryptis tetraporophora	Eyrean earless		✓	✓			
Boidae							
Antaresia stimsoni	Stimson's python	SA I	✓	✓			
Aspidites ramsayi	Woma python		✓				
Elapidae							
Demansia reticulata	Desert whipsnake		✓	✓			
Pseudechis australis	Mulga snake		✓	✓			
Pseudonaja modesta	Five-ringed snake		✓	✓			
Pseudonaja nuchalis	Western brown snake		✓	✓			
Simoselaps bertholdi	Desert banded snake		✓	✓			
Simoselaps fascioltus	Narrow-banded snake		✓				
Suta suta	Curl snake		✓	✓			

Scientific name	Common name	Status	Regional occurrence[1]	Arcoona tableland[2]	Recorded in field survey		
					40a	45a	52a
Gekkonidae							
Diplodactylus conspicillatus	Fat-tailed gecko		✓				
Diplodactylus damaeus	Beaded gecko		✓	✓			
Diplodactylus stenodactylus	Sandplain gecko		✓	✓			
Diplodactylus tessellatus	Tessellated gecko		✓	✓			
Diplodactylus vittatus	Eastern stone gecko		✓				
Gehyra purpurascens	Purple dtella		✓				
Gehyra variegata	Tree dtella		✓	✓			
Heteronotia binoei	Bynoe’s Binoe’s gecko		✓	✓			
Nephrurus levis	Smooth knob-tailed gecko		✓	✓			
Nephrurus milii	Barking gecko		✓	✓			
Rhynchoedura ornata	Beaked gecko		✓				
Strophurus ciliaris	Northern spiny-tailed gecko		✓	✓			
Strophurus intermedius	Southern spiny-tailed gecko		✓	✓			
Pygopodidae							
Delma australis	Barred snake-lizard		✓	✓			
Pygopus lepidopodus	Common scalyfoot		✓	✓			
Pygopus nigriceps	Black-headed scalyfoot		✓	✓			
Scincidae							
Cryptoblepharus carnabyi			✓	✓			
Cryptoblepharus plagiocephalus	Desert wall skink		✓	✓			
Ctenotus brooksi taeniatus	Sandhill ctenotus		✓	✓			
Ctenotus leae	Centralian coppertail		✓	✓			
Ctenotus leonhardii	Common desert ctenotus		✓				
Ctenotus olympicus			✓	✓			
Ctenotus regius	Eastern desert ctenotus		✓	✓			
Ctenotus robustus	Eastern striped skink		✓	✓			
Ctenotus schomburgkii	Sandplain ctenotus		✓	✓			
Ctenotus strauchii	Short-legged ctenotus		✓	✓			
Egernia stokesii	Gidgee skink		✓	✓			

					Recorded in field survey		
Scientific name	**Common name**	**Status**	**Regional occurrence**[(1)]	**Arcoona tableland**[(2)]	**40a**	**45a**	**52a**
Eremiascincus richardsonii	Broad banded sand swimmer		✓	✓			
Lerista bougainvillii	Bouganville's skink		✓	✓			
Lerista desertorum	Great desert slider		✓				
Lerista dorsalis	Southern four-toed slider		✓	✓			
Lerista edwardsae	Myall slides		✓	✓			
Lerista labialis	Eastern two-toed slider		✓	✓			
Lerista Muelleri	Dwarf three-toed slider		✓	✓			
Menetia greyii	Dwarf skink		✓	✓			
Morethia adelaidensis	Adelaide snake-eye		✓	✓			
Morethia boulengeri	Common snake-eye		✓	✓			
Tiliqua occipitalis	Western bluetongue		✓	✓			
Tiliqua rugosa	Sleepy lizard		✓	✓			
Typhlopidae							
Ramphotyphlops bituberculatus	Rough-nosed blind snake		✓	✓			
Ramphotyphlops endoterus	Centralian blind snake		✓	✓			
Varanidae							
Varanus gilleni	Pygmy mulga goanna		✓	✓			
Varanus gouldii	Sand goanna		✓	✓			
AMPHIBIAN							
Neobatrachus centralis	Trilling frog		✓	✓			

(1) Kinhill Engineers Pty Ltd (1997) and SA Museum
(2) Brandle R (1998) SA Museum and J Read (pers. comm. January 2001)

APPENDIX E

Appendix E

RADIATION

E1 Radiological Measurements of the Proposed Repository Sites
Australian Radiation Protection and Nuclear Safety Agency

E2 Woomera Soils Report
Australian Radiation Protection and Nuclear Safety Agency

E3 Baseline Atmospheric Radioactivity Monitoring
On Site Technology Pty Ltd

E4 Radioanalytical Analysis of Flora from the Woomera Gibber Plains
Australian Nuclear Science and Technology Organisation

E5 Radioactivity Analysis Report — Fauna and Water
Australian Radiation Protection and Nuclear Safety Agency

E6 Calculation of Radiological Risks to Construction Workers
RWE Nukem

E7 Radiological Risks Arising through Missile or Aircraft Impact in the Operational Phase
RWE Nukem

E8 Post Institutional Control Risk Assessment
SERCO Assurance

Appendix E1
Radiological Measurements of the Proposed Repository Sites

This appendix reports on a survey of the proposed and two alternative sites to determine their pre-existing radiological content.

E1.1 Introduction

The Department of Industry, Science and Resources (DISR) commissioned the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) to undertake a survey of the three sites near Woomera proposed as candidates for the national low level and short-lived intermediate radioactive waste repository. The purpose of this survey was to determine the pre-existing radiological content of the three areas and ensure that none of the proposed sites had anomalous radioactive content.

The field survey was conducted over two field trips in October and November 2000. The field monitoring consisted of obtaining several high-resolution gamma-ray spectra at each site using the purpose-designed vehicle operated by ARPANSA. This vehicle enables a high-purity germanium detector to be raised 4 m above the ground.

This procedure allows gamma rays emitted from the soil, within an approximately 40 m radius, to be detected and analysed. The detector was calibrated for the range of gamma rays emitted by the decay of ^{40}K and the decay series associated with ^{232}Th and ^{238}U, the three radionuclides commonly found in soil. Therefore, the activity concentrations of potassium, thorium and uranium within an area of approximately 5000 m^2 could be determined by each measurement.

Furthermore, any gamma rays not associated with these common radionuclides would be measured and could be investigated. However, the only other radionuclide detected at a statistically significant level was ^{137}Cs, produced by the global fallout from nuclear weapons and accidents, and found throughout Australia and the world. At each site, a spectrum was collected at each of approximately 12 different areas.

Five soil samples were also collected from each of two areas at each site. The analyses of these samples in the ARPANSA laboratory were used to complement the in-situ monitoring. These measurements were analysed using the following assumptions:

- All gamma rays detected during the in-situ measurements were emitted by the soil.
- The radionuclides of interest are uniformly distributed with depth.
- The soil is a uniform stratum to a depth of at least 50 cm.
- The radioactive progeny of uranium and thorium are in equilibrium with their parent radionuclides.
- Samples taken from the top 10 cm of soil are representative of the entire soil column.

Unfortunately, the exhalation of a fraction of the radon, a gaseous radionuclide produced during the decay of thorium and uranium, from the top layer of soil into the atmosphere means that these assumptions are only approximations. Nonetheless, the measurements do provide an estimate of the uranium and thorium content of the soil to better than a factor of two. For radionuclides with less complicated decay chains, such as ^{137}Cs and ^{40}K, however, they do provide very accurate measurements and assumptions about their radiochemistry are not required.

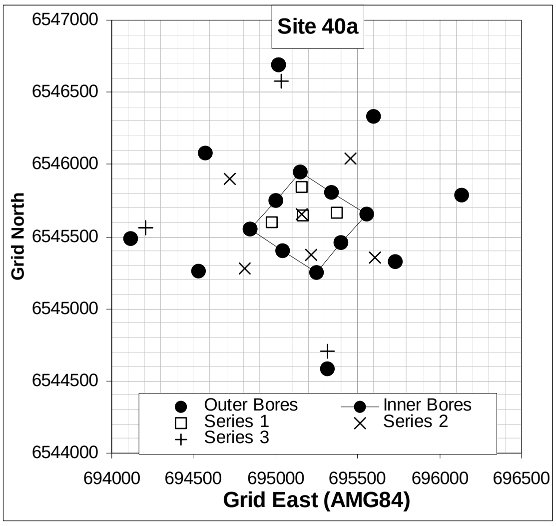
E1.2 Results

Table E1.1 gives a summary of radionuclide concentrations measured at each of the three sites and Figure E1.1 shows the measurement positions.

TABLE E1.1 Radionuclide levels measured in soils

Radionuclide	Measurement	Site 40a	Site 45a	Site 52a
^{232}Th (Bq/kg)	In-situ average	41 ± 5	39 ± 3	51 ± 8
	In-situ range	35–54	35–43	46–71
	Soil sample range	26–39	24–36	20–32
^{238}U (Bq/kg)	In-situ average	29 ± 4	35 ± 6	45 ± 21
	In-situ range	25–36	29–49	37–99
	Soil sample range	17–23	13–21	15–21
^{40}K (Bq/kg)	In-situ average	348 ± 45	335 ± 24	323 ± 22
	In-situ range	283–393	293–372	288–331
	Soil sample range	287–366	260–347	190–335
^{137}Cs (Bq/kg)	In-situ average	2.3 ± 1.2	2.1 ± 0.8	2.8 ± 1.0
	In-situ range	0.0–4.0	0.8–3.2	1.5–4.2
	Soil sample range	0.7–2.3	0.5–3.8	1.1–5.6

Errors quoted to 1 standard deviation



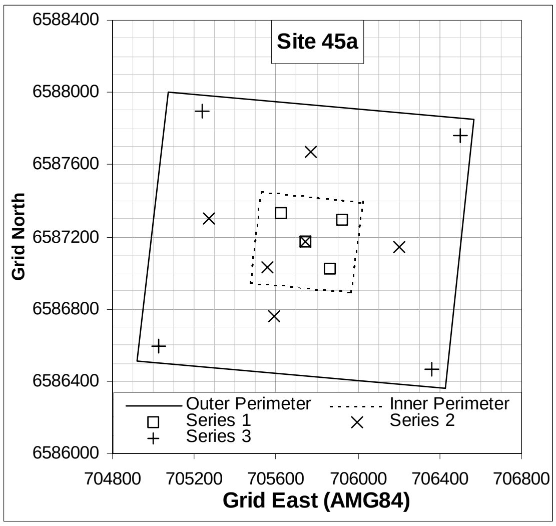


FIGURE E1.1
Measurement positions

The radionuclide measurements correlate well with the typical values found worldwide of:

- 30 Bq/kg for ^{232}Th
- 35 Bq/kg for ^{238}U
- 400 Bq/kg for ^{40}K.

The results for each of the radionuclides measured, ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs, are given in Tables E1.2–E1.5.

TABLE E1.2 Summary of uranium measurements

^{238}Uranium (Bq/kg)						
Measurement number	**Coordinates (AMG84)**		**In-situ measurement**		**Soil sample averages**	
	East	**North**				
NWR40-1A	695164	6545650	25	± 9	19	± 1
NWR40-1B	695376	6545664	29	± 5		
NWR40-1C	694975	6545596	27	± 5		
NWR40-1D	695158	6545839	25	± 4		
NWR40-2A	695161	6545651	31	± 4		
NWR40-2B	695214	6545377	27	± 7		
NWR40-2C	694810	6545282	36	± 6		
NWR40-2D	695605	6545355	26	± 5		
NWR40-2E	695457	6546042	30	± 6		
NWR40-2F	694720	6545897	28	± 7		
NWR40-3A	695035	6546576	36	± 5		
NWR40-3B	694211	6545558	24	± 5		
NWR40-3C	695316	6544704	33	± 7		
NWR40-3D	694211	6545559	30	± 6	20	± 3
Site 40a average			**29**	**± 4**		
NWR45-1A	705746	6587174	33	± 7	19	± 3
NWR45-1B	705622	6587334	32	± 11		
NWR45-1C	705862	6587021	29	± 7		
NWR45-1D	705923	6587291	31	± 4		
NWR45-2A	705747	6587174	38	± 11		
NWR45-2B	705560	6587028	31	± 6		
NWR45-2C	705269	6587303	33	± 8		
NWR45-2D	706201	6587142	32	± 6		
NWR45-2E	705771	6587669	30	± 5		
NWR45-2F	705590	6586757	35	± 6		
NWR45-3A	706499	6587762	46	± 12	16	± 3
NWR45-3B	706364	6586470	49	± 7		
NWR45-3C	705028	6586592	38	± 7		
NWR45-3D	705240	6587899	37	± 6		
Site 45a average			**35**	**± 6**		
NWR52-1A	636958	6573641	37	± 11	16	± 1
NWR52-2A	636912	6573560	37	± 4		
NWR52-2B	636883	6573689	37	± 8		
NWR52-2C	637032	6573601	39	± 11		
NWR52-2D	637014	6573738	37	± 6		
NWR52-3A	637946	6573851	51	± 7		
NWR52-3B	636370	6574147	99	± 52	18	± 2
NWR52-3C	637308	6573650	94	± 21		
NWR52-3D	636557	6573070	57	± 10		
Site 52a average			**45**	**± 21**		

To convert these measurements to weight fractions, divide by 12.44×10^6 Bq/kg.

TABLE E1.3 Summary of thorium measurements

^{232}Thorium (Bq/kg)						
Measurement number	**Coordinates (AMG84)**		**In-situ measurement**		**Soil sample averages**	
	East	**North**				
NWR40-1A	695164	6545650	41	± 8	32	± 4
NWR40-1B	695376	6545664	42	± 7		
NWR40-1C	694975	6545596	44	± 6		
NWR40-1D	695158	6545839	35	± 6		
NWR40-2A	695161	6545651	41	± 7		
NWR40-2B	695214	6545377	37	± 6		
NWR40-2C	694810	6545282	44	± 8		
NWR40-2D	695605	6545355	39	± 7		
NWR40-2E	695457	6546042	40	± 7		
NWR40-2F	694720	6545897	39	± 6		
NWR40-3A	695035	6546576	54	± 10		
NWR40-3B	694211	6545558	33	± 6		
NWR40-3C	695316	6544704	49	± 13		
NWR40-3D	694211	6545559	44	± 10	34	± 3
Site 40a average			**41**	**± 5**		
NWR45-1A	705746	6587174	36	± 6	32	± 3
NWR45-1B	705622	6587334	39	± 7		
NWR45-1C	705862	6587021	35	± 6		
NWR45-1D	705923	6587291	35	± 4		
NWR45-2A	705747	6587174	41	± 5		
NWR45-2B	705560	6587028	40	± 5		
NWR45-2C	705269	6587303	39	± 6		
NWR45-2D	706201	6587142	36	± 4		
NWR45-2E	705771	6587669	40	± 6		
NWR45-2F	705590	6586757	41	± 6		
NWR45-3A	706499	6587762	42	± 9	27	± 3
NWR45-3B	706364	6586470	43	± 7		
NWR45-3C	705028	6586592	39	± 6		
NWR45-3D	705240	6587899	44	± 10		
Site 45a average			**39**	**± 3**		
NWR52-1A	636958	6573641	52	± 8	25	± 3
NWR52-2A	636912	6573560	46	± 7		
NWR52-2B	636883	6573689	50	± 9		
NWR52-2C	637032	6573601	54	± 12		
NWR52-2D	637014	6573738	47	± 8		
NWR52-3A	637946	6573851	47	± 9		
NWR52-3B	636370	6574147	55	± 10	30	± 2
NWR52-3C	637308	6573650	71	± 18		
NWR52-3D	636557	6573070	46	± 9		
Site 52a average			**51**	**± 8**		

To convert these measurements to weight fractions, divide by 40.58×10^6 Bq/kg.

TABLE E1.4 Summary of potassium measurements

^{40}Potassium (Bq/kg)						
Measurement number	**Coordinates (AMG84)**		**In-situ measurement**		**Soil sample averages**	
	East	**North**				
NWR40-1A	695164	6545650	393	± 11	343	± 31
NWR40-1B	695376	6545664	362	± 10		
NWR40-1C	694975	6545596	436	± 11		
NWR40-1D	695158	6545839	283	± 10		
NWR40-2A	695161	6545651	370	± 11		
NWR40-2B	695214	6545377	326	± 11		
NWR40-2C	694810	6545282	375	± 11		
NWR40-2D	695605	6545355	301	± 10		
NWR40-2E	695457	6546042	382	± 11		
NWR40-2F	694720	6545897	364	± 11		
NWR40-3A	695035	6546576	349	± 11		
NWR40-3B	694211	6545558	268	± 9		
NWR40-3C	695316	6544704	331	± 10		
NWR40-3D	694211	6545559	357	± 10	332	± 26
Site 40a average			**348**	**± 45**		
NWR45-1A	705746	6587174	354	± 10	324	± 20
NWR45-1B	705622	6587334	324	± 10		
NWR45-1C	705862	6587021	354	± 11		
NWR45-1D	705923	6587291	324	± 10		
NWR45-2A	705747	6587174	354	± 10		
NWR45-2B	705560	6587028	362	± 11		
NWR45-2C	705269	6587303	319	± 10		
NWR45-2D	706201	6587142	293	± 10		
NWR45-2E	705771	6587669	331	± 11		
NWR45-2F	705590	6586757	347	± 10		
NWR45-3A	706499	6587762	352	± 11	297	± 22
NWR45-3B	706364	6586470	372	± 11		
NWR45-3C	705028	6586592	314	± 10		
NWR45-3D	705240	6587899	306	± 10		
Site 45a average			**335**	**± 24**		
NWR52-1A	636958	6573641	331	± 11	248	± 42
NWR52-2A	636912	6573560	331	± 10		
NWR52-2B	636883	6573689	329	± 10		
NWR52-2C	637032	6573601	357	± 11		
NWR52-2D	637014	6573738	321	± 10		
NWR52-3A	637946	6573851	331	± 10		
NWR52-3B	636370	6574147	308	± 10	295	± 45
NWR52-3C	637308	6573650	288	± 10		
NWR52-3D	636557	6573070	314	± 10		
Site 52a average			**323**	**± 22**		

To convert these measurements to weight fractions, divide by 209.1×10^6 Bq/kg.

TABLE E1.5 Summary of caesium measurements

^{137}Caesium (Bq/kg)						
Measurement number	**Coordinates (AMG84)**		**In-situ measurement**		**Soil sample averages**	
	East	**North**				
NWR40-1A	695164	6545650	2.9	± 0.8	1.1	± 0.6
NWR40-1B	695376	6545664	2.7	± 1.0		
NWR40-1C	694975	6545596	0.0	± 2.4		
NWR40-1D	695158	6545839	0.0	± 2.4		
NWR40-2A	695161	6545651	2.8	± 0.8		
NWR40-2B	695214	6545377	1.4	± 0.8		
NWR40-2C	694810	6545282	4.0	± 0.9		
NWR40-2D	695605	6545355	2.6	± 0.8		
NWR40-2E	695457	6546042	3.4	± 0.8		
NWR40-2F	694720	6545897	1.8	± 0.8		
NWR40-3A	695035	6546576	0.9	± 0.9		
NWR40-3B	694211	6545558	2.5	± 1.0		
NWR40-3C	695316	6544704	1.9	± 0.8		
NWR40-3D	694211	6545559	2.1	± 0.8	1.2	± 0.7
Site 40a average			**2.3**	**± 1.2**		
NWR45-1A	705746	6587174	3.1	± 0.9	2.2	± 1.1
NWR45-1B	705622	6587334	3.0	± 0.8		
NWR45-1C	705862	6587021	1.9	± 0.8		
NWR45-1D	705923	6587291	2.0	± 0.8		
NWR45-2A	705747	6587174	3.2	± 0.9		
NWR45-2B	705560	6587028	2.9	± 0.9		
NWR45-2C	705269	6587303	2.0	± 0.9		
NWR45-2D	706201	6587142	1.0	± 0.8		
NWR45-2E	705771	6587669	2.6	± 0.8		
NWR45-2F	705590	6586757	2.8	± 1.0		
NWR45-3A	706499	6587762	2.3	± 0.9	1.8	± 0.8
NWR45-3B	706364	6586470	2.3	± 1.0		
NWR45-3C	705028	6586592	1.0	± 0.9		
NWR45-3D	705240	6587899	0.8	± 1.0		
Site 45a average			**2.2**	**± 0.8**		
NWR52-1A	636958	6573641	3.3	± 0.9	2.9	± 1.5
NWR52-2A	636912	6573560	2.7	± 0.9		
NWR52-2B	636883	6573689	3.8	± 0.9		
NWR52-2C	637032	6573601	1.6	± 1.0		
NWR52-2D	637014	6573738	2.4	± 0.8		
NWR52-3A	637946	6573851	4.2	± 1.0		
NWR52-3B	636370	6574147	3.2	± 1.2	2.0	± 1.0
NWR52-3C	637308	6573650	3.1	± 1.2		
NWR52-3D	636557	6573070	1.5	± 0.9		
Site 52a average			**2.8**	**± 1.0**		

To convert these measurements to weight fractions, divide by 3.219×10^{15} Bq/kg.

It should be noted that the range of concentration values for each nuclide varies markedly with soil type and geographic region. Indeed, a recent study of the Darling Scarp in Australia (Alach et al. 1996) found values in the range 53–500 Bq/kg for ^{232}Th and 22–110 Bq/kg for ^{238}U.

For the purposes of comparison with chemical analyses, these activity concentrations correspond to approximately 10 parts per million of thorium and 3 parts per million of uranium. As a matter of interest, the concentrations for caesium (which is a different isotope to that naturally occurring, ^{133}Cs) correspond to approximately 7 parts of ^{137}Cs in 10^{16} parts of soil.

Therefore, these measurements show that the radiological content of the soils at these sites is similar to that found in most Australian soils

E1.3 Reference

Alach, ZJ, Breheny, RS, Broun and Toussaint, LF. 1996. Radionuclide concentrations in the Darling Scarp of Western Australia. Radiation Protection in Australia, 14, 35–38.

Appendix E2
Woomera Soils Report

This appendix reports on the physical properties of the soils at the proposed site and two alternative sites for the national repository.

Samples were received from three sites near Woomera, identified as 40a, 45a and 52a. Two drill cores were provided from each site, hence there was a total of six cores varying in total depth, from 28 m to 34.4 m. All of the rocks were sedimentary in origin and varied between quartzites with harder sandstones and mudstones with softer sandstones, with an upper topsoil layer.

The samples were sorted, physically described and their details recorded.

It was determined to firstly test samples at three different depth intervals; viz. the surface topsoils, at approximately 15 m, and also around 30 m. One sample from each core was taken from these approximate depths. If two samples from similar depths happened to be very similar lithologies, then an alternate sample was taken from the next closest depth. Where appropriate, additional samples were taken from various depths, in order to test all of the various lithologies present.

The samples were prepared for testing. This required crushing, by means of a hydraulic press and also by mortar and pestle, then grinding in a Retsch Cross Beater Mill. Some samples required drying before crushing and grinding. The samples were then analysed by high resolution gamma spectrometry and results for ^{235}U, ^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{228}Ra, ^{228}Th, ^{137}Cs, ^{60}Co and ^{40}K contents are reported. No other radionuclides were observed.

Upon completion of this first pass, the results were reviewed and several samples were re-run (i.e. samples with the notation S1-2). There was one sample (0422) with relatively higher activity values, and hence some of the surrounding samples were counted (from the same site and another nearby site).

The results were collated in three different ways. Firstly, the samples were arranged in rock lithologies, see Table E2.1. This was done according to the size of the grains and the physical hardness of the sample. For example, mudstone has the smallest grain size and is the easiest to crush, while quartzite has larger grain size and is the hardest to crush.

The results were also arranged in intervals of depth (see Table E2.2). There is one sample from each site in the main three groups; viz. near surface samples, samples at approximately 15 m, and samples at approximately 30 m. The remaining samples were then arranged between these main three groups. Lastly, the results were arranged in site locations and by depth within those site locations (see Table E2.3).

Summary Tables E2.4, E2.5 and E2.6 were composed by taking the minimum and maximum values from Tables E2.1, E2.2 and E2.3 respectively. The following radionuclides were chosen for tabulating: ^{235}U, ^{238}U, ^{226}Ra, ^{210}Pb, ^{228}Ra and ^{228}Th. Table E2.6, which lists samples grouped by site locations, shows the greatest ranges of activity values. In this case, several different types of lithologies have been grouped together and this observation is in agreement with the indication (Table E2.4) that, in general, similar lithologies have similar radioactive concentrations.

One sample (0422 – purple mudstone, Site 45aNW) had significantly elevated levels of activity in both the Th and U series. The reasons for this are unclear, although this sample was atypical in that it easily crushed to a very fine, powdery red dust. In the summary tables (Tables E2.4, E2.5 and E2.6) the mudstone 0422 was both included and excluded in the related groups, in order to show that without sample 0422, the groups had normal low activity levels. Several samples surrounding the sample 0422 were counted. These showed similar activities to the majority of the samples, that is non-elevated.

A number of samples, including 0422, were measured twice. These duplicates showed good reproducibility, and in most cases the results agreed within the uncertainty range.

For the most active sample, duplicate analyses were performed on the sample sealed in a resin matrix. Results showed reasonably good agreement, indicating that secular equilibrium was present in all samples, including those not sealed in resin.

In general, mudstones and soft sandstone are expected to be more permeable to water than the other lithologies and these sample types showed the highest radioactivity concentrations (Table E2.4). The harder lithologies, hard sandstones and quartzites, showed lower activities.

The tables show the activity concentrations for the important gamma-ray emitting members of the natural ^{238}U and ^{232}Th decay series. The deviations from secular equilibrium are generally small, except in some surface soils where levels of ^{210}Pb, and perhaps ^{226}Ra exceed the levels of ^{238}U.

The fractions, by mass, of the U and Th parent elements may be obtained by dividing the activity concentrations by 12.44×10^6 and 4.058×10^6, respectively.

TABLE E2.1 Radionuclide activity (Bq/kg) (grouped by lithologies)

Sample no. and	Location			^{238}U series				^{232}Th series				K
type of rock	Site	Depth (m)	^{235}U	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th	^{137}Cs	^{60}Co	^{40}K
Near surface topsoils												
(0389S1–1) red clayey topsoil	40aE	0–0.7	1.1 (0.2)	< 14	< 70	17.8 (0.4)	29 (5)	31 (1)	29.3 (0.5)	< 0.8	< 1.0	326 (8)
(0389S1–2) red clayey topsoil	40aE	0–0.7	1.0 (0.2)	13 (4)	< 58	18.0 (0.4)	25 (4)	30.0 (0.9)	29.6 (0.4)	1.0 (0.1)	< 0.8	337 (8)
(0399) red clay topsoil	40aW	0–1.0	1.4 (0.1)	20 (3)	< 35	19.4 (0.3)	26 (3)	35.8 (0.7)	34.7 (0.4)	< 0.5	< 0.5	404 (8)
(0409) red clay topsoil	45aSE	0–0.75	0.9 (0.2)	18 (4)	< 53	18.4 (0.3)	26 (4)	31.7 (0.8)	31.1 (0.4)	0.7 (0.2)	< 0.7	411 (10)
(0417) dark red/brown soil	45aNW	0–0.75	1.0 (0.2)	23 (4)	< 52	18.2 (0.3)	20 (4)	27.8 (0.8)	27.5 (0.4)	< 0.7	< 0.7	298 (8)
(0425) orange/red topsoil	52aE	0–1.0	1.2 (0.2)	16 (4)	< 87	19.4 (0.4)	23 (4)	35.6 (0.9)	36.8 (0.5)	< 0.8	< 0.8	423 (10)
(0434) red/brown topsoil	52aW	0–1.0	1.1 (0.2)	25 (4)	< 58	16.8 (0.4)	15 (4)	26.9 (0.8)	26.2 (0.4)	< 0.8	< 0.8	252 (7)
Mudstones												
(0412) green mudstone	45aSE	11.0–11.3	2.0 (0.2)	39 (6)	< 77	34.2 (0.5)	33 (6)	67 (2)	68.8 (0.8)	< 1.0	< 1.1	1164 (24)
(0437) yellow mudstone (hard)	52aW	15.5–15.9	< 0.7	< 13	< 67	11.5 (0.4)	21 (5)	45 (1)	46.1 (0.6)	< 0.9	< 0.9	267 (8)
(0422S1–1) purple mudstone	45aNW	23.6–23.9	19.2 (0.8)	385 (35)	339 (78)	405 (3)	479 (19)	99 (2)	103 (1)	< 1.8	< 1.9	1682 (35)
(0422S1–2) purple mudstone	45aNW	23.6–23.9	17.8 (0.8)	384 (35)	348 (80)	452 (3)	457 (18)	100 (2)	104 (1)	< 1.9	< 2.0	1708 (35)
(0439) grey sandstone (v.soft)	52aW	27.6–28.0	1.3 (0.2)	39 (5)	< 93	34.5 (0.4)	32 (4)	32.7 (0.8)	32.8 (0.5)	< 0.7	< 0.8	191 (6)
(0407) green mud (v.soft)	40aW	34.2–34.4	2.1 (0.2)	41 (6)	< 75	44.6 (0.6)	52 (6)	36 (1)	37.8 (0.5)	< 1.0	< 1.2	1427 (29)
Soft sandstones												
(0391) pink sandstone	40aE	5.1–5.5	3.1 (0.2)	71 (7)	< 88	59.6 (0.6)	71 (5)	65 (1)	67.5 (0.7)	< 0.7	< 0.6	64 (3)
(0428) mottled sandstone	52aE	6.8–7.1	1.9 (0.2)	34 (5)	< 57	33.0 (0.5)	46 (4)	16.2 (0.7)	15.9 (0.3)	< 0.7	< 0.8	176 (6)
(0429) grey sandstone (s)	52aE	11.9–12.2	0.5 (0.1)	17 (3)	< 39	12.5 (0.3)	11 (3)	12.6 (0.5)	13.5 (0.2)	< 0.5	< 0.5	213 (5)
(0420S1–1) grey sandstone (s)	45aNW	13.65–13.95	0.6 (0.1)	13 (3)	< 37	11.3 (0.2)	15 (3)	11.3 (0.4)	12.3 (0.2)	< 0.5	< 0.5	236 (6)
(0420S1–2) grey sandstone (s)	45aNW	13.65–13.95	0.6 (0.1)	10 (3)	< 37	12.1 (0.2)	16 (3)	12.1 (0.4)	12.0 (0.2)	< 0.5	< 0.5	249 (6)
(0431S1–1) red sandstone	52aE	20.95–21.3	1.6 (0.2)	31 (5)	< 65	33.0 (0.4)	32 (5)	58 (1)	56.9 (0.7)	< 0.8	< 0.8	531 (12)
(0431S1–2) red sandstone	52aE	20.95–21.3	1.1 (0.2)	36 (5)	< 64	34.1 (0.4)	33 (4)	54 (1)	56.8 (0.7)	< 0.8	< 0.8	531 (12)

Sample no. and type of rock	Location: Site	Location: Depth (m)	^{235}U	^{238}U series: ^{238}U	^{238}U series: ^{230}Th	^{238}U series: ^{226}Ra	^{238}U series: ^{210}Pb	^{232}Th series: ^{228}Ra	^{232}Th series: ^{228}Th	^{137}Cs	^{60}Co	K: ^{40}K
Moderately hard sandstones												
(0413) grey sandstone (s)	45aSE	14.9–15.2	< 0.5	< 9	< 42	10.0 (0.2)	17 (3)	17.8 (0.6)	17.5 (0.3)	< 0.6	< 0.6	357 (8)
(0421) pale grey sandstone (s)	45aNW	17.7–18.0	0.8 (0.1)	12 (3)	< 47	13.4 (0.3)	15 (3)	26.2 (0.7)	26.2 (0.4)	< 0.6	< 0.7	446 (10)
(0416) purple sandstone	45aSE	29.9–30.3	< 0.4	12 (3)	< 44	14.9 (0.3)	21 (3)	22.3 (0.6)	22.5 (0.3)	< 0.6	< 0.6	371 (8)
(0433S1–1) orange sandstone	52aE	31.2–31.6	< 0.4	< 8	< 35	6.2 (0.1)	9 (3)	6.6 (0.4)	6.4 (0.2)	< 0.5	< 0.6	248 (6)
(0433S1–2) orange sandstone	52aE	31.2–31.6	< 0.3	8 (2)	< 21	6.0 (0.1)	11 (2)	6.4 (0.2)	6.4 (0.1)	< 0.3	< 0.3	235 (5)
(0424) purple sandstone	45aNW	31.5–31.9	0.4 (0.1)	11 (2)	< 23	11.8 (0.2)	13 (2)	13.5 (0.3)	13.1 (0.2)	< 0.3	< 0.3	338 (7)
Hard sandstones and cong.												
(0426) mottled cg	52aE	1.8–2.2	1.3 (0.2)	31 (4)	< 44	38.5 (0.4)	33 (3)	18.8 (0.6)	18.9 (0.3)	< 0.5	< 0.5	14 (2)
(0423) grey sandstone (hard)	45aNW	25.0–25.3	0.3 (0.1)	7 (2)	< 21	8.9 (0.1)	9 (2)	10.4 (0.3)	10.4 (0.2)	< 0.3	< 0.3	247 (5)
(0415) purple sandstone (hard)	45aSE	25.1–25.4	0.9 (0.1)	20 (3)	< 42	16.9 (0.3)	18 (3)	16.4 (0.5)	16.2 (0.3)	< 0.5	< 0.6	360 (8)
(0397) grey sandstone (hard)	40aE	30.7–31.0	< 0.4	9 (2)	< 31	8.2 (0.2)	12 (2)	6.4 (0.4)	6.2 (0.1)	< 0.3	< 0.5	139 (4)
(0406) grey sandstone (hard)	40aW	31.2–31.55	0.4 (0.1)	7 (2)	< 29	6.0 (0.2)	< 8	6.1 (0.3)	6.0 (0.1)	< 0.4	< 0.4	18 (2)
Very hard quartzites												
(0410) grey quartzite	45aSE	4.2–4.5	0.7 (0.1)	18 (3)	< 41	20.4 (0.3)	22 (3)	15.8 (0.5)	15.8 (0.3)	< 0.5	< 0.5	7 (2)
(0393) grey quartzite	40aE	13.6–13.9	0.3 (0.1)	8 (2)	< 19	7.6 (0.1)	8 (2)	7.1 (0.2)	7.2 (0.1)	< 0.2	< 0.2	40 (2)
(0403) grey quartzite	40aW	15.1–15.4	< 0.3	7 (2)	< 28	4.4 (0.2)	8 (2)	5.7 (0.3)	6.0 (0.1)	< 0.4	< 0.4	13 (2)

cg = conglomerate; s = soft; v.soft = very soft

TABLE E2.2 Radionuclide activity (Bq/kg) (grouped by intervals of depth)

Sample no. and	Location			^{238}U series				^{232}Th series				K
type of rock	Site	Depth (m)	^{235}U	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th	^{137}Cs	^{60}Co	^{40}K
Near surface topsoils												
(0389S1-1) red clayey topsoil	40aE	0–0.7	1.1 (0.2)	< 14	< 70	17.8 (0.4)	29 (5)	31 (1)	29.3 (0.5)	< 0.8	< 1.0	326 (9)
(0389S1-2) red clayey topsoil	40aE	0–0.7	1.0 (0.2)	13 (4)	< 58	18.0 (0.4)	25 (4)	30.0 (0.9)	29.6 (0.4)	1.0 (0.1)	< 0.8	337 (8)
(0399) red clay topsoil	40aW	0–1.0	1.4 (0.1)	20 (3)	< 35	19.4 (0.3)	26 (3)	35.8 (0.7)	34.7 (0.4)	< 0.5	< 0.5	404 (8)
(0409) red clay topsoil	45aSE	0–0.75	0.9 (0.2)	18 (4)	< 53	18.4 (0.3)	26 (4)	31.7 (0.8)	31.1 (0.4)	0.7 (0.2)	< 0.7	411 (10)
(0417) dark red/brown soil	45aNW	0–0.75	1.0 (0.2)	23 (4)	< 52	18.2 (0.3)	20 (4)	27.8 (0.8)	27.5 (0.4)	< 0.7	< 0.7	298 (8)
(0425) orange/red topsoil	52aE	0–1.0	1.2 (0.2)	16 (4)	< 87	19.4 (0.4)	23 (4)	35.6 (0.9)	36.8 (0.5)	< 0.8	< 0.8	423 (10)
(0434) red/brown topsoil	52aW	0–1.0	1.1 (0.2)	25 (4)	< 58	16.8 (0.4)	15 (4)	26.9 (0.8)	26.2 (0.4)	< 0.8	< 0.8	252 (7)
Selected samples 1–15 m												
(0426) mottled cg	52aE	1.8–2.2	1.3 (0.2)	31 (4)	< 44	38.5 (0.4)	33 (3)	18.8 (0.6)	18.9 (0.3)	< 0.5	< 0.5	14 (2)
(0410) grey quartzite	45aSE	4.2–4.5	0.7 (0.1)	18 (3)	< 41	20.4 (0.3)	22 (3)	15.8 (0.5)	15.8 (0.3)	< 0.5	< 0.5	7 (2)
(0391) pink sandstone	40aE	5.1–5.5	3.1 (0.2)	71 (7)	< 88	59.6 (0.6)	71 (5)	65 (1)	67.5 (0.7)	< 0.7	< 0.6	64 (3)
(0428) mottled sandstone	52aE	6.8–7.1	1.9 (0.2)	34 (5)	< 57	33.0 (0.5)	46 (4)	16.2 (0.7)	15.9 (0.3)	< 0.7	< 0.8	176 (6)
(0412) green mudstone	45aSE	11.0–11.3	2.0 (0.2)	39 (6)	< 77	34.2 (0.5)	33 (6)	67 (2)	68.8 (0.8)	< 1.0	< 1.1	1164 (24)
Samples approx. 15 m												
(0429) grey sandstone (s)	52aE	11.9–12.2	0.5 (0.1)	17 (3)	< 39	12.5 (0.3)	11 (3)	12.6 (0.5)	13.5 (0.2)	< 0.5	< 0.5	213 (5)
(0393) grey quartzite	40aE	13.6–13.9	0.3 (0.1)	8 (2)	< 19	7.6 (0.1)	8 (2)	7.1 (0.2)	7.2 (0.1)	< 0.2	< 0.2	40 (2)
(0420S1–1) grey sandstone (s)	45aNW	13.65–13.95	0.6 (0.1)	13 (3)	< 37	11.3 (0.2)	15 (3)	11.3 (0.4)	12.3 (0.2)	< 0.5	< 0.5	236 (6)
(0420S1–2) grey sandstone (s)	45aNW	13.65–13.95	0.6 (0.1)	10 (3)	< 37	12.1 (0.2)	16 (3)	12.1 (0.4)	12.0 (0.2)	< 0.5	< 0.5	249 (6)
(0413) grey sandstone (s)	45aSE	14.9–15.2	< 0.5	< 9	< 42	10.0 (0.2)	17 (3)	17.8 (0.6)	17.5 (0.3)	< 0.6	< 0.6	357 (8)
(0403) grey quartzite	40aW	15.1–15.4	< 0.3	7 (2)	< 28	4.4 (0.2)	8 (2)	5.7 (0.3)	6.0 (0.1)	< 0.4	< 0.4	13 (2)
(0437) yellow mudstone	52aW	15.5–15.9	< 0.7	< 13	< 67	11.5 (0.4)	21 (5)	45 (1)	46.1 (0.6)	< 0.9	< 0.9	267 (8)
Selected samples 15–30 m												
(0421) pale grey sandstone	45aNW	17.7–18.0	0.8 (0.1)	12 (3)	< 47	13.4 (0.3)	15 (3)	26.2 (0.7)	26.2 (0.4)	< 0.6	< 0.7	446 (10)
(0431S1–1) red sandstone	52aE	20.95–21.3	1.6 (0.2)	31 (5)	< 65	33.0 (0.4)	32 (5)	58 (1)	56.9 (0.7)	< 0.8	< 0.8	531 (12)

Sample no. and type of rock	Location			^{238}U series				^{232}Th series				K
	Site	Depth (m)	^{235}U	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th	^{137}Cs	^{60}Co	^{40}K
(0431S1–2) red sandstone	52aE	20.95–21.3	1.1 (0.2)	36 (5)	< 64	34.1 (0.4)	33 (4)	54 (1)	56.8 (0.7)	< 0.8	< 0.8	531 (12)
(0422S1–1) purple mudstone	45aNW	23.6–23.9	19.2 (0.8)	385 (35)	339 (78)	405 (3)	479 (19)	99 (2)	103 (1)	< 1.8	< 1.9	1682 (35)
(0422S1–2) purple mudstone	45aNW	23.6–23.9	17.8 (0.8)	384 (35)	348 (80)	452 (3)	457 (18)	100 (2)	104 (1)	< 1.9	< 2.0	1708 (35)
(0415) grey sandstone	45aSE	25.1–25.4	0.9 (0.1)	20 (3)	< 42	16.9 (0.3)	18 (3)	16.4 (0.5)	16.2 (0.3)	< 0.5	< 0.6	360 (8)
Samples approx. 30 m												
(0416) purple sandstone	45aSE	29.9–30.3	< 0.4	12 (3)	< 44	14.9 (0.3)	21 (3)	22.3 (0.6)	22.5 (0.3)	< 0.6	< 0.6	371 (8)
(0423) grey sandstone (hard)	45aNW	25.0–25.3	0.3 (0.1)	7 (2)	< 21	8.9 (0.1)	9 (2)	10.4 (0.3)	10.4 (0.2)	< 0.3	< 0.3	247 (5)
(0397) grey sandstone (hard)	40aE	30.7–31.0	< 0.4	9 (2)	< 31	8.2 (0.2)	12 (2)	6.4 (0.4)	6.2 (0.1)	< 0.3	< 0.5	139 (4)
(0406) grey sandstone (hard)	40aW	31.2–31.55	0.4 (0.1)	7 (2)	< 29	6.0 (0.2)	< 8	6.1 (0.3)	6.0 (0.1)	< 0.4	< 0.4	18 (2)
(0439) grey sandstone (v.soft)	52aW	27.6–28.0	1.3 (0.2)	39 (5)	< 93	34.5 (0.4)	32 (4)	32.7 (0.8)	32.8 (0.5)	< 0.7	< 0.8	191 (6)
(0433S1–1) orange sandstone	52aE	31.2–31.6	< 0.4	< 8	< 35	6.2 (0.1)	9 (3)	6.6 (0.4)	6.4 (0.2)	< 0.5	< 0.6	248 (6)
(0433S1–2) orange sandstone	52aE	31.2–31.6	< 0.3	8 (2)	< 21	6.0 (0.1)	11 (2)	6.4 (0.2)	6.4 (0.1)	< 0.3	< 0.3	235 (5)
Selected samples deeper than 30 m												
(0424) purple sandstone	45aNW	31.5–31.9	0.4 (0.1)	11 (2)	< 23	11.8 (0.2)	13 (2)	13.5 (0.3)	13.1 (0.2)	< 0.3	< 0.3	338 (7)
(0407) green mud	40aW	34.2–34.4	2.1 (0.2)	41 (6)	< 75	44.6 (0.6)	52 (6)	36 (1)	37.8 (0.5)	< 1.0	< 1.2	1427 (29)

cg = conglomerate; s = soft; v.soft = very soft

TABLE E2.3 Radionuclide activity (Bq/kg) (grouped by site locations)

Sample no. and	Location			^{238}U series				^{232}Th series				K
type of rock	Site	Depth (m)	^{235}U	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th	^{137}Cs	^{60}Co	^{40}K
Site 40aE												
(0389S1–1) red clayey topsoil	40aE	0–0.7	1.1 (0.2)	< 14	< 70	17.8 (0.4)	29 (5)	31 (1)	29.3 (0.5)	< 0.8	< 1.0	326 (9)
(0389S1–2) red clayey topsoil	40aE	0–0.7	1.0 (0.2)	13 (4)	< 58	18.0 (0.4)	25 (4)	30.0 (0.9)	29.6 (0.4)	1.0 (0.1)	< 0.8	337 (8)
(0391) pink sandstone	40aE	5.1–5.5	3.1 (0.2)	71 (7)	< 88	59.6 (0.6)	71 (5)	65 (1)	67.5 (0.7)	< 0.7	< 0.6	64 (3)
(0393) grey quartzite	40aE	13.6–13.9	0.3 (0.1)	8 (2)	< 19	7.6 (0.1)	8 (2)	7.1 (0.2)	7.2 (0.1)	< 0.2	< 0.2	40 (2)
(0397) grey sandstone (hard)	40aE	30.7–31.0	< 0.4	9 (2)	< 31	8.2 (0.2)	12 (2)	6.4 (0.4)	6.2 (0.1)	< 0.3	< 0.5	139 (4)
Site 40aW												
(0399) red clay topsoil	40aW	0–1.0	1.4 (0.1)	20 (3)	< 35	19.4 (0.3)	26 (3)	35.8 (0.7)	34.7 (0.4)	< 0.5	< 0.5	404 (8)
(0403) grey quartzite	40aW	15.1–15.4	< 0.3	7 (2)	< 28	4.4 (0.2)	8 (2)	5.7 (0.3)	6.0 (0.1)	< 0.4	< 0.4	13 (2)
(0406) grey sandstone (hard)	40aW	31.2–31.55	0.4 (0.1)	7 (2)	< 29	6.0 (0.2)	< 8	6.1 (0.3)	6.0 (0.1)	< 0.4	< 0.4	18 (2)
(0407) green mud	40aW	34.2–34.4	2.1 (0.2)	41 (6)	< 75	44.6 (0.6)	52 (6)	36 (1)	37.8 (0.5)	< 1.0	< 1.2	1427 (29)
Site 45aSE												
(0409) red clay topsoil	45aSE	0–0.75	0.9 (0.2)	18 (4)	< 53	18.4 (0.3)	26 (4)	31.7 (0.8)	31.1 (0.4)	0.7 (0.2)	< 0.7	411 (10)
(0410) grey quartzite	45aSE	4.2–4.5	0.7 (0.1)	18 (3)	< 41	20.4 (0.3)	22 (3)	15.8 (0.5)	15.8 (0.3)	< 0.5	< 0.5	7 (2)
(0412) green mudstone	45aSE	11.0–11.3	2.0 (0.2)	39 (6)	< 77	34.2 (0.5)	33 (6)	67 (2)	68.8 (0.8)	< 1.0	< 1.1	1164 (24)
(0413) grey sandstone (s)	45aSE	14.9–15.2	< 0.5	< 9	< 42	10.0 (0.2)	17 (3)	17.8 (0.6)	17.5 (0.3)	< 0.6	< 0.6	357 (8)
(0415) grey sandstone	45aSE	25.1–25.4	0.9 (0.1)	20 (3)	< 42	16.9 (0.3)	18 (3)	16.4 (0.5)	16.2 (0.3)	< 0.5	< 0.6	360 (8)
(0416) purple sandstone	45aSE	29.9–30.3	< 0.4	12 (3)	< 44	14.9 (0.3)	21 (3)	22.3 (0.6)	22.5 (0.3)	< 0.6	< 0.6	371 (8)
Site 45aNW												
(0417) dark red/brown soil	45aNW	0–0.75	1.0 (0.2)	23 (4)	< 52	18.2 (0.3)	20 (4)	27.8 (0.8)	27.5 (0.4)	< 0.7	< 0.7	298 (8)
(0420S1–1) grey sandstone (s)	45aNW	13.65–13.95	0.6 (0.1)	13 (3)	< 37	11.3 (0.2)	15 (3)	11.3 (0.4)	12.3 (0.2)	< 0.5	< 0.5	236 (6)
(0420S1–2) grey sandstone (s)	45aNW	13.65–13.95	0.6 (0.1)	10 (3)	< 37	12.1 (0.2)	16 (3)	12.1 (0.4)	12.0 (0.2)	< 0.5	< 0.5	249 (6)
(0421) pale grey sandstone	45aNW	17.7–18.0	0.8 (0.1)	12 (3)	< 47	13.4 (0.3)	15 (3)	26.2 (0.7)	26.2 (0.4)	< 0.6	< 0.7	446 (10)
(0422S1–1) purple mudstone	45aNW	23.6–23.9	19.2 (0.8)	385 (35)	339 (78)	405 (3)	479 (19)	99 (2)	103 (1)	< 1.8	< 1.9	1682 (35)
(0422S1–2) purple mudstone	45aNW	23.6–23.9	17.8 (0.8)	384 (35)	348 (80)	452 (3)	457 (18)	100 (2)	104 (1)	< 1.9	< 2.0	1708 (35)

Sample no. and type of rock	Location			^{238}U series				^{232}Th series				K
	Site	Depth (m)	^{235}U	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th	^{137}Cs	^{60}Co	^{40}K
(0423) grey sandstone (hard)	45aNW	25.0–25.3	0.3 (0.1)	7 (2)	< 21	8.9 (0.1)	9 (2)	10.4 (0.3)	10.4 (0.2)	< 0.3	< 0.3	247 (5)
(0424) purple sandstone	45aNW	31.5–31.9	0.4 (0.1)	11 (2)	< 23	11.8 (0.2)	13 (2)	13.5 (0.3)	13.1 (0.2)	< 0.3	< 0.3	338 (7)
Site 52aE												
(0425) orange/red topsoil	52aE	0–1.0	1.2 (0.2)	16 (4)	< 87	19.4 (0.4)	23 (4)	35.6 (0.9)	36.8 (0.5)	< 0.8	< 0.8	423 (10)
(0426) mottled cg	52aE	1.8–2.2	1.3 (0.2)	31 (4)	< 44	38.5 (0.4)	33 (3)	18.8 (0.6)	18.9 (0.3)	< 0.5	< 0.5	14 (2)
(0428) mottled sandstone	52aE	6.8–7.1	1.9 (0.2)	34 (5)	< 57	33.0 (0.5)	46 (4)	16.2 (0.7)	15.9 (0.3)	< 0.7	< 0.8	176 (6)
(0429) grey sandstone (s)	52aE	11.9–12.2	0.5 (0.1)	17 (3)	< 39	12.5 (0.3)	11 (3)	12.6 (0.5)	13.5 (0.2)	< 0.5	< 0.5	213 (5)
(0431S1–1) red sandstone	52aE	20.95–21.3	1.6 (0.2)	31 (5)	< 65	33.0 (0.4)	32 (5)	58 (1)	56.9 (0.7)	< 0.8	< 0.8	531 (12)
(0431S1–2) red sandstone	52aE	20.95–21.3	1.1 (0.2)	36 (5)	< 64	34.1 (0.4)	33 (4)	54 (1)	56.8 (0.7)	< 0.8	< 0.8	531 (12)
(0433S1–1) orange sandstone	52aE	31.2–31.6	< 0.4	< 8	< 35	6.2 (0.1)	9 (3)	6.6 (0.4)	6.4 (0.2)	< 0.5	< 0.6	248 (6)
(0433S1–2) orange sandstone	52aE	31.2–31.6	< 0.3	8 (2)	< 21	6.0 (0.1)	11 (2)	6.4 (0.2)	6.4 (0.1)	< 0.3	< 0.3	235 (5)
Site 52aW												
(0434) red/brown topsoil	52aW	0–1.0	1.1 (0.2)	25 (4)	< 58	16.8 (0.4)	15 (4)	26.9 (0.8)	26.2 (0.4)	< 0.8	< 0.8	252 (7)
(0437) yellow mudstone	52aW	15.5–15.9	< 0.7	< 13	< 67	11.5 (0.4)	21 (5)	45 (1)	46.1 (0.6)	< 0.9	< 0.9	267 (8)
(0439) grey sandstone (v.soft)	52aW	27.6–28.0	1.3 (0.2)	39 (5)	< 93	34.5 (0.4)	32 (4)	32.7 (0.8)	32.8 (0.5)	< 0.7	< 0.8	191 (6)

cg = conglomerate; s = soft; v.soft = very soft

TABLE E2.4 Summary of radionuclide activity (Bq/kg) (grouped by lithologies)

Sample no. and type of rock	^{235}U	^{238}U series			^{232}Th series	
		^{238}U	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th
Near surface topsoils	0.9–1.4	13–25	16–20	15–29	26–36	26–37
Mudstones (including 0422)	<0.7–19	< 13–385	11–452	21–479	32–100	32–104
Mudstone (excluding 0422)	<0.7–2.1	<13–41	11–45	21–52	32–67	32–69
Soft sandstones	0.5–3.1	10–71	11–60	11–71	11–65	12–68
Moderately hard sandstones	< 0.3–0.8	< 8–12	6–15	9–21	6–27	6–27
Hard sandstones and conglomerate	< 0.4–1.3	7–31	6–39	< 8–33	6–19	6–19
Very hard quartzites	< 0.3–0.7	7–18	4–21	8–22	5–16	6–16

TABLE E2.5 Summary of radionuclide activity (Bq/kg) (grouped by intervals of depth)

Sample no. and type of rock	^{235}U	^{238}U series			^{232}Th series	
		^{238}U	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th
Near surface topsoils	0.9–1.4	13–25	16–20	15–29	26–36	26–37
Selected samples 1–15 m	0.7–3.1	18–71	20–60	22–71	15–67	15–69
Samples at approx. 15 m	< 0.3–0.6	7–17	4–13	8–21	5–45	6–47
Selected samples 15–30 m (including 0422)	0.8–19	12–385	13–452	15–479	16–100	16–104
Selected samples 15–30 m (excluding 0422)	0.8–1.6	12–36	13–35	15–33	16–58	16–57
Samples at approx. 30 m	< 0.3–1.3	7 –39	6–35	< 8–32	6–33	6–33
Selected samples deeper than 30 m	0.4–2.1	11–41	11–45	13–52	13–36	13–38

TABLE E2.6 Summary of radionuclide activity (Bq/kg) (grouped in site locations)

Sample no. and type of rock	^{235}U	^{238}U series			^{232}Th series	
		^{238}U	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th
Site 40aE	0.3–3.1	8–71	7–60	8–71	6–65	6–68
Site 40aW	< 0.3–2.1	7–41	4–45	< 8–52	5–36	6–38
Site 45aSE	< 0.4–2.0	< 9–39	10–35	17–33	15–67	15–69
Site 45aNW (including 0422)	0.3–19	7–385	8–452	9–479	10–100	10–104
Site 45aNW (excluding 0422)	0.3–1.0	7–23	8–19	9–20	10–28	10–28
Site 52aE	< 0.3–1.9	< 8–36	6–39	9–46	6–58	6–57
Site 52aW	< 0.7–1.3	< 13–39	11–35	15–32	26–45	26–47

Appendix E3
Baseline Atmospheric Radioactivity Monitoring

This appendix details the results of field and laboratory measurements by On Site Technology Pty Ltd to estimate background airborne radionuclide levels at the three potential repository sites.

E3.1 Site Visits

The two site visits undertaken for baseline atmospheric radioactivity monitoring were conducted with the approval of the Bureau of Rural Sciences under section 10 of the *Land Acquisitions Act 1989* (Cwlth). Bureau staff were present during all field activities.

During the first visit, 24–26 September 2001, passive dust fall gauges and passive radon monitors were deployed at each site. In addition radon daughter samplers were deployed for a 24-hour period at Sites 45a and 52a (duplicate samples). Radon daughter sampling was not undertaken at Site 40a because access to the site for retrieval of the sampler after 24 hours could not be guaranteed due to degradation of the access track by approximately 14 mm of rain that fell on 24 September.

During the second visit, between 10–12 December 2001, the passive dust fall gauges and passive radon monitors were retrieved. In addition, radon daughter monitors were deployed for a 24-hour period at each site. Surface soil samples were collected and background ionising radiation dose rate measured at each site.

E3.2 Rationale for Selected Approach

Usually a background survey would be conducted over a minimum of a full year in order to estimate the impacts of seasonal variations. The current study was limited to approximately three months because:

- The three sites were still being investigated and a detailed and complete background study would be conducted on the site finally chosen for the repository.
- Background data covering a number of years at the WMC Olympic Dam operation were available.
- Time constraints imposed by the Commonwealth's desire to prepare an environmental impact statement by early 2002 precluded a full year's monitoring.
- There was a lack of infrastructure at the sites, for example access problems at Site 40a and 45a and lack of power at all locations.

Passive dust deposition gauges were used instead of high volume samplers because they provide an average result for the whole monitoring period, do not require power and have a negligible impact on the sampling site. High volume air samplers were not considered a cost-effective or practical alternative because:

- There is no power at the sites under investigation.
- Installation of samplers and generators would result in a permanent impact on the sites (e.g. concrete pads).
- Access problems at Sites 40a and 45a would restrict the number of samples that could be collected.
- The substantial cost of installation and maintenance of high volume samplers at three sites was not justified at this stage considering that additional background monitoring will be conducted when the final site is selected.

E3.3 Methodology

E3.3.1 Passive Dust Sampling

Passive dust sampling was conducted according to Australian Standard AS 3580. 10. 1–1991 with the following modifications:

- Sampling was conducted over 78 days instead of the 30 days specified in the standard to collect the maximum amount of dust possible to facilitate radiochemical analysis.
- Plastic funnels were used instead of the glass funnels specified in the standard because previous experience has shown these are less prone to breakage in remote locations.
- Plastic sample containers were used instead of the glass containers specified in the standard so that the containers could be cut open to facilitate removal of fine dust adhering to the container wall.

Samplers were deployed in duplicate (approximately 12 metres apart) so that an estimate of method error could be made. The deployment of duplicate samplers also afforded some protection against the loss of data resulting from damage to the sampler by stock or wildlife.

Some difficulty was experienced at Site 45a because of an excessive number of insects (locusts) that collected in the gauge. This is discussed in detail in the results section of the report.

E3.3.2 Passive Radon Monitors

Radon monitors were supplied and analysed by Radiation Detection Systems. These passive detectors based on a proprietary track etching system developed by Radiation Detection Systems and have been calibrated in radon chambers at Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and the South Australian Department of Human Services (SA DHS) Radiation Section.

Radon monitors were deployed for the full 78-day monitoring period and provide an average radon concentration for that period.

E3.3.3 Radon Daughter Monitors

Radon daughter monitors were supplied and analysed by Radiation Detection Systems. These are active detectors based on a proprietary track etching system developed by Radiation Detection Systems and have been calibrated in radon chambers at ARPANSA and the SA DHS Radiation Section.

Radon daughter samples were collected at each site over a 24-hour period on two occasions. For the September sampling trip duplicate samples were collected at Site 52a because access problems prevented sampling at Site 40a.

E3.3.4 Uranium and Thorium Analysis

Dust and soil samples were analysed for uranium and thorium by inductively coupled plasma mass spectrometry (ICP-MS) after total digestion of the sample by a mixed acid (including hydrofluoric acid) digest. Analysis was undertaken at the geochemical laboratory of Amdel Ltd.

The ICP-MS results for uranium and thorium were used to calculate activity for ^{238}U and ^{232}Th.

E3.3.5 Gamma Spectrometry

After pulverising, approximately 60 g of each sample was cast in an epoxy resin disc approximately 11 mm thick and 85 mm in diameter. These discs were analysed by high resolution gamma spectrometry (HRGS) for a number of naturally occurring and man made radio isotopes.

Dust samples were cast in an epoxy resin disc approximately 25 mm in diameter and 3 mm thick for HRGS analysis.

Counting efficiency for uranium and thorium daughters was determined by analysis of certified reference materials cast into the same geometry as the samples. Counting efficiency for potassium was determined by the analysis of reagent grade potassium chloride cast into the same geometry as the samples.

Counting efficiencies for ^{137}Cs and ^{60}Co were estimated by the analysis of counting standards with a geometry approximately the same as the samples. This calibration method results in a higher error than the method used for uranium and thorium daughters, but the error is not significant because ^{137}Cs and ^{60}Co were not detected in any of the samples. The estimated counting efficiencies were only used to estimate detection limits.

E3.3.6 Ionising Radiation Dose Rate

Dose rate was determined at each site with a Ludlum model 19 dose rate meter. The meter was calibrated at the SA DHS Radiation Section. Measurements were taken at a height of 1 m above the ground.

E3.3.7 Dust

Results from the dust deposition gauges are presented in Table E3.1.

E3.4 Results and Discussion

Significant error is introduced into the results for Site 45a because of the presence of a large amount of insect matter in the collected samples. The samples from Sites 40a and 52a contained small quantities of insect matter (1–5 mg) which is typical for dust deposition gauges. However the samples from Site 45a contained 100–500 mg (after drying) of insect matter identified as locusts. The presence of these insects is probably related to the exceptionally high rainfall at the site during the sampling period. The insect matter was removed from these samples and treated separately. In Table E3.1 the results for the insect matter from Site 45a are reported in brackets after the results for the dust. For the other two sites the insect matter was removed for weighing but included in the dust for analysis.

The significant amount of insect matter in the samples from Site 45a introduces errors for the following reasons:

- Broken insect parts could not be completely separated from the dust sample so the measured collected dust mass is higher than the actual dust mass.
- It is probable that the insects were contaminated with soil when they died in the collection device, this additional dust would elevate the calculated deposition rate above the actual deposition rate.

Some correction for the effects of the first source of error can be made by using the ash results from Sites 40a and 52a to estimate the amount of insect matter remaining in the dust portion of the samples from Site 45a. This correction is possible because the ash value for the dust is approximately 49% while the ash value for the insect matter is in the range 1–8%. Based on these figures the corrected deposition rates for Site 45a are approximately 34% of the values reported in Table E3.1, that is, 48 and 93 mg/m^2/d.

There is no practical way of correcting for the second source of error other than to state that this would result in an elevated calculated deposition rate. For this reason the corrected deposition rates for Site 45a (48 and 93 mg/m^2/d) should be considered as upper limits for the actual deposition rate.

TABLE E3.1 Results from deposition gauges

Site	40a	40a	45a	45a	52a	52a	Units
Location	53J	53J	53J	53J	53J	53J	
	0695144	0695116	0705766	0705767	0636775	0636776	east
	6545658	6545660	6587202	6587207	6574567	6574585	north
Set up							
Time	10:25	10:25	15:25	15:25	10:30	10:30	
Date	24/9/01	24/9/01	24/9/01	14/9/01	25/9/01	25/9/01	
Collection							
Time	14:31	14:31	10:25	10:25	14:23	14:23	
Date	11/12/01	11/12/01	12/12/01	12/12/01	12/12/01	12/12/01	
# days sampled	78	78	79	79	78	78	
Sample	40a (1)	40a(2)	45a (1)	45a (2)	52a (1)	52a (2)	
Water collected	833.7	864.8	2290.5	2216.8	982.5	995.8	ml
Calculated rainfall	43.6	45.2	119.8	116.0	51.4	52.1	mm
Dust collected							
All matter	0.7747	0.10184	0.71645	0.54952	0.05179	0.02529	g
Insects	0.00313	0.00359	0.50250	0.13752	0.00460	0.00171	g
Dust	0.07434	0.09825	0.21395	0.41200	0.04719	0.02358	g
Ash							
All matter	0.03285	0.05807			0.02360	0.01310	g
Insects			0.03929	0.00183			g
Dust			0.02187	0.12171			g
Ash							
All matter	42	57			46	52	%
Insects			7.8	1.3			%
Dust			10	30			%
Uranium	1.00		1.65 (0.77)		1.67		µg/g
Thorium	2.70		1.65 (3.8)		1.10		µg/g
Calculated deposition							
Dust	50	66	142	273	32	16	$mg/m^2/d$
Ash	22	39	14	81	16	8.8	$mg/m^2/d$
Uranium	0.050		0.234		0.021		$\mu g/m^2/d$
Thorium	0.135		0.234		0.035		$\mu g/m^2/d$
^{238}U	0.6		2.9		0.3		$mBq/m^2/d$
^{226}Ra		<20		<20		<20	$mBq/m^2/d$
^{210}Pb		120		310		140	$mBq/m^2/d$
^{232}Th	0.6		1.0		0.1		$mBq/m^2/d$
^{228}Ac		<20		<20		<20	$mBq/m^2/d$
^{228}Th		<20		<20		<20	$mBq/m^2/d$
^{137}Cs		<20		<20		<20	$mBq/m^2/d$
^{60}Co		<20		<20		<20	$mBq/m^2/d$
^{40}K		<20		<20		<20	$mBq/m^2/d$

The rainfall calculated for Site 45a (118 mm) is significantly higher than that calculated for Sites 40a (44. 4 mm) and 52a (51. 7 mm). It is also significantly higher than the Bureau of Meteorology (BOM) rainfall recorded over the sampling period at Woomera aerodrome (74. 6 mm) and Roxby Downs aerodrome (62. 4 mm).

Based on BOM data the average rainfall for the September to December period is 48. 8 mm for Woomera and 54. 7 mm at Roxby Downs. This indicates that the rainfall at Site 45a was atypically high during the sampling period. This factor must be taken into account when considering the results.

Notwithstanding the comments made concerning the results from Site 45a the results obtained during this investigation are comparable to those reported by the WMC's Olympic Dam operation for sampling sites to the north (Site 13) and south (Site 14) of their operation between 1996 and 2001. These results and comparisons are summarised in Table E3.2.

TABLE E3.2 Comparison of deposition gauge results

Data Source	Site	Dust	^{238}U	^{226}R	^{210}Pb	Note
		mg/m^2/d	mBq/m^2/d	mBq/m^2/d	mBq/m^2/d	
This study	40a	50	0.6			
	40a	66		<20	120	
	45a	48	0.9			Corrected
	45a	93		<20	100	Corrected
	52a	32	0.3			
	52a	16		<20	140	
WMC's results	13	36–88	0–1.5	0–5.7	66–99	Range
	13	61	0.6	3	81	Average
	14	40–95	0–1.4	0.03–9	104–148	Range
	14	62	0.7	3	132	Average

E3.4.1 Radionuclides in Soil

Results for the analysis of soil samples collected from each site are presented in Table E3.3.

TABLE E3.3 Results of soil analysis

Site	40a	45a	52a	Units
Location	53J	53J	53J	
	0695144	0705766	0636775	east
	6545658	6587202	6574597	north
Date	11/12/01	12/12/01	12/12/01	
Uranium	1.00	0.91	0.70	µg/g
Thorium	9.50	7.00	6.00	µg/g
^{238}U	12	11	9	mBq/g
^{226}Ra	13	8	5	mBq/g
^{210}Pb	28	51	100	mBq/g
^{232}Th	39	29	25	mBq/g
^{228}Ac	25	23	21	mBq/g
^{228}Th	26	23	18	mBq/g
^{137}Cs	<10	<10	<10	mBq/g
^{60}Co	<10	<10	<10	mBq/g
^{40}K	110	74	46	mBq/g
Dose rate	<0.05	<0.05	<0.05	USv/h

Surface soils samples were collected from the top few mm of soil and screened through a 0.5 mm mesh to remove plant matter and course material. The intention was to obtain a sample that represented the local material that would easily become airborne.

The surface soil samples are similar in radiochemical make up to the dust material collected in the deposition gauges except that the soil has a higher level of thorium and thorium daughter products than the deposited dust. The average thorium value for the soil samples was 7.5 µg/g while the average value for the deposited dust was 1.8 µg/g. This could be the result of thorium being associated with dense minerals that are less prone to becoming airborne, however the further investigation of this anomaly is beyond the scope of the current study.

It is of note that the insect matter from Site 45a also showed an elevated thorium level (3.8 µg/g) which supports the possibility that the insects are contaminated with soil and result in an elevation of the calculated deposition rate for Site 45a. There are other possible reasons for elevated thorium levels in the insects (e.g. preferential uptake of thorium by insects) however further investigation is beyond the scope of this study.

E3.4.2 Radon

Radon results are tabulated in Table E3.4. Results represent the average radon (^{222}Rn) concentration over the sampling period of 78 (or 79) days. The results are typical of average open air radon concentrations.

Because the results represent an average value they do not reflect the diurnal and seasonal variations that are typical of open air radon levels.

TABLE E3.4 Radon results

Site	40a	45a	52a	Units
Location	53J	53J	53J	
	0695144	0705766	0636775	east
	6545658	6587202	6574597	north
Monitor ID	JW3Q/13	JW3Q/12	JW3Q/14	
Set up				
Time	10:25	15:25	10:30	
Date	24/9/01	24/9/01	25/9/01	
Collection				
Time	14:31	10:25	14:23	
Date	11/12/01	12/12/01	12/12/01	
# days sampled	78	79	78	
Radon	55	59	39	Bq/m^3

E3.4.3 Radon Daughters

Radon daughter results are tabulated in Table E3.5.

WMC's Olympic Dam operation has provided results of their radon daughter monitoring program for four sites. The data consisted of average values for each month for the years 1991 to 2001 for each month at their four monitoring sites, and is presented graphically in Figure E3.1. These average concentrations were obtained by averaging the results for each month so that the result plotted for January (for example) is the average January result between 1991 and 2001. This was done to indicate any seasonal variation in results.

TABLE E3.5 Radon daughter results

Site	40a	45a	45a	52a	52a	52a	Units
Location	53J	53J	53J	53J	53J	53J	
	0695144	0705766	0705766	0636775	0636776	0636775	east
	6545658	6587202	6587202	6574597	6574585	6574597	
Sample	1	1	2	1	2	3	
Start							
Date	10/12/01	24/9/01	11/12/01	25/9/01	25/9/01	10/12/01	
Time	13:22	15:35	10:45	10:30	10:32	10:37	
Stop							
Date	11/12/01	25/9/01	12/12/01	26/9/01	26/9/01	12/12/01	
Time	14:31	15:35	10:25	10:30	10:32	14:23	
Sampler	JW01-4Q/12	JW01-3Q/13	JW01-4Q/14	JW01-3Q/12	JW01-3Q/14	JW01-4Q/13	
Result	0.059	0.048	0.060	0.048	0.050	0.037	UJ/m^{3}PAEC
Result	2.8	2.3	2.9	2.3	2.4	1.8	mWl

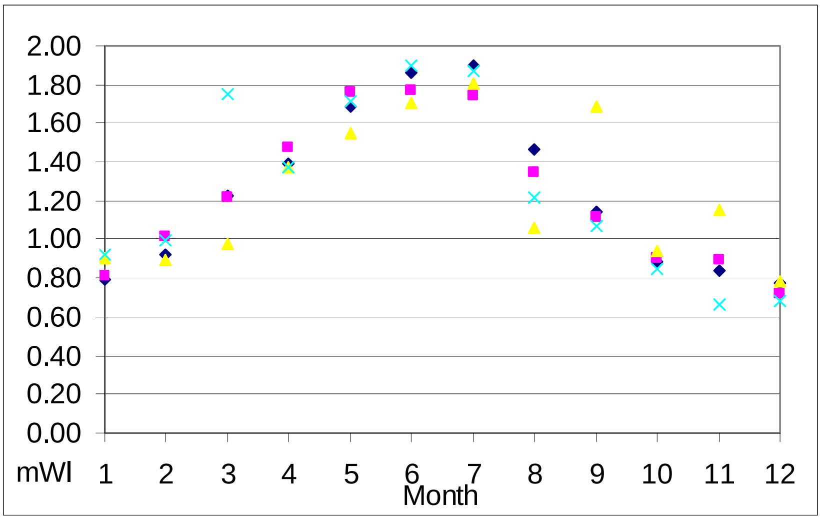


FIGURE E3.1
WMC Olympic Dam average radon daughter results

The key difference between the Olympic Dam results and the results of monitoring at the three sites under investigation is that the latter results are higher than the former. The results for the four locations near the Olympic Dam site vary from 0.01 (in summer) to 0.04 (in winter) uJ/m^3 PAEC (i.e. 0.6 to 2.0 milli working levels) whereas the results for the sites under investigation vary from 0. 04 to 0. 06 uJ/m^3 PAEC (i.e. 1.8 to 2.9 milli working levels).

There are a number of possible reasons for this difference including the following:

- The higher than average rainfall just before the sampling in September and December may have resulted in higher than average radon daughter levels. Note that this is the reverse of the expected trend but is supported by the increased average values reported for Olympic Dam in the winter months.

- The typical radon daughter levels at the sites under investigation may in fact be higher than the levels around the Olympic Dam site. This could be due to the Olympic Dam sites being in (primarily) dune country and the sites under investigation are in gibber plain areas.
- The data set from the sites under investigation (six results) may be too small to draw any statistically significant conclusion.
- Meteorological conditions on the sampling days may not have been typical for the area.
- There may be differences in the methodology used in this study and the WMC study.

A detailed assessment of the reason for this apparent discrepancy is beyond the scope of this investigation. However, future investigations should follow up on this.

In any case the radon daughter results for September and December for the three sites under investigation are low and typical of an open air environment. There is no statistical difference between the results from the three sites investigated.

E3.5 Acknowledgements

The preparation of this report was greatly assisted by the provision of monitoring data from WMC's Olympic Dam operation. The cooperation of Mr Mike Worby in providing the data is acknowledged with appreciation.

Meteorological data was provided by the Climate and Consultancy Section of the South Australian Regional Office, Bureau of Meteorology.

The assistance of staff from the Bureau of Rural Sciences during the field trips is gratefully acknowledged.

Appendix E4 Radioanalytical Analysis of Flora Samples from the Woomera Gibber Plains

This appendix provides an analysis of the radionuclide content of plants of the Woomera gibber plains particularly in the vicinity of the proposed and alternative sites for the national repository. This study was undertaken by the Australian Nuclear Science and Technical Organisation (ANSTO).

E4.1 Introduction

The purpose of the study was to address issues associated with the environmental impact study for the national repository as well as to provide baseline data for quality assurance of produce and foodstuffs to graziers and other interested parties in the region.

E4.2 Method

Approximately 2 kg (fresh weight) samples of the plant species *Atriplex vesicaria* (bladder saltbush), Eragrostis australasica (canegrass) and *Sclerostegia medullosa* (samphire) were collected at each of 3 field sites on the Woomera gibber plains, Australia. On return to the laboratory the samples where washed to remove any surface contamination.

The washing procedure involved dividing each specimen into approximately 3–5 smaller portions which were then wrapped in nylon fine gauge 'mosquito' netting. Each portion was then fully immersed in a 10 L solution containing 5 g of EDTA and 5 g of Decon 90 detergent for approximately 30 seconds and then allowed to drain. This procedure was repeated twice more before the portion was transferred to another bucket containing 10 L of de-ionised water. The portion was then rinsed three times by immersion for 30 seconds followed by draining for 30 seconds. The EDTA / Decon-90 washing solution was changed between specimens and before the final rinse of each portion. After washing the portions were transferred to a stainless fine mesh cage and plunged into liquid nitrogen in order to render the material brittle. Whilst immersed under nitrogen the now frozen material was subjected to repeated manual compressions causing some of the specimen to shatter leading to a reduced sample volume. On removal from the nitrogen the material was further crushed and then the portions recombined prior to carefully packing the specimens into pre-weighed stainless steel ashing trays. The specimens were then dried in an oven over several days to constant weight (variable temperature 40–110ºC to remove moisture).

Oven dried samples were allowed to cool to ambient temperature, weighed and then transferred to a muffle furnace for ashing at 450ºC (ramp rate 1ºC per minute). After cooling to ambient temperature the ashing tray plus sample was reweighed and the ashed material transferred to a plastic bottle, capped and the bottle vigorously shaken for several minutes to fully homogenise the contents.

Subsamples of each specimen where then packed into a 55 mm Petrie dish, the lid sealed onto the base with silicon glue and the dish gamma counted on a Canberra Industries (Meriden, USA) Compton Suppression Gamma Spectrometer (HPGe, 50% relative efficiency). The suppressed spectrum was used to analyse ^{241}Am at 59.5 keV, ^{226}Ra at 186 keV and ^{137}Cs at 662 keV and the unsuppressed spectrum was used to analyse ^{60}Co at 1173 keV and 1332 keV.

E4.3 Results

The activity of the vegetation specimens was determined by comparison with the standards IAEA AG-B-1 (marine alga) (^{60}Co, ^{137}Cs and ^{226}Ra) and IAEA 308 (seaweed) (^{241}Am). The results for the four isotopes studied are given in Table E4.1.

TABLE E4.1 Isotope activity in vegetation specimens

Site	ANSTO ID	Am-241 (Bq/kg)	Co-60 (Bq/kg)	Cs-137 (Bq/kg)	Ra-226 (Bq/kg)
***Atriplex vesicaria* (bladder saltbush)**					
40a	C512	Not detected MDA = 0.32	Not detected MDA = 0.96	0.26+/-0.10 (36.8%)	Not detected MDA = 2.52
45a	C513	Not detected MDA = 0.29	Not detected MDA = 0.90	0.25+/-0.10 (39.3%)	Not detected MDA = 2.05
52a	C514	Not detected MDA = 0.34	Not detected MDA = 0.99	Not detected MDA = 0.99	Not detected MDA = 2.70
***Eragrostis australasica* (canegrass)**					
40a	C515	Not detected MDA = 0.13	Not detected MDA = 0.49	0.10+/-0.05 (51.4%)	Not detected MDA = 1.54
45a	C516#2	Not detected MDA = 0.11	Not detected MDA = 0.33	Not detected MDA = 0.33	Not detected MDA = 0.78
52a	C517#2	Not detected MDA = 0.06	Not detected MDA = 0.21	0.07+/-0.03 (34.8%)	Not detected MDA = 0.48
***Sclerostegia medullosa* (samphire)**					
40a	C509	Not detected MDA = 0.24	Not detected MDA = 0.85	Not detected MDA = 0.85	Not detected MDA = 2.13
45a	C510	Not detected MDA = 0.24	Not detected MDA = 0.81	Not detected MDA = 0.81	Not detected MDA = 1.95
52a	C511	Not detected MDA = 0.23	Not detected MDA = 0.77	0.18+/-0.09 (46.7%)	Not detected MDA = 2.15

MDA = minimum detectable amount (95% confidence interval)

E4.4 Discussion

Gamma spectrometry analysis of the flora samples obtained from the Woomera Gibber Plains failed to show the presence of ^{241}Am, ^{60}Co or ^{226}Ra within the limits of detection. Additionally just over half of the samples showed measurable quantities of ^{137}Cs. These results suggest that specimens have not been subjected to any significant quantities of radioactive fallout and that the traces of ^{137}Cs present in some samples may be considered consistent with general background levels.

E4.5 References

Davy, DR and Conway, NF. 1974. Environmental studies, Northern Territory uranium province, 1971–73. Report 3 in The Alligator Rivers Area Fact Finding Study, Four AAEC.

Davy, DR. 1975. Referred to in URANCFS. See: Williams AR. 1983. Biogeochemistry of 226Ra in a tropical wetland, N.T. Paper 74 (Vol. 2) in Environmental Protection in the Alligator Rivers Region. Scientific Workshop, Jabiru NT, 17–20 May 1983.

Giles, MS and Evans, JV. 1987. Concentration of radium in acid swamp soils in the Northern Territory. Radiation Protection in Australia 1987, 5(1), 14–18.

Lowson, RT and Williams AR. 1985. A baseline radioecological survey, Manyingee uranium prospect, WA. Report to Total Mining Australia Pty Ltd. AAEC/C47.

E4.6 Attachment A

John Twining (ANSTO) has supplied data sets of ^{226}Ra and ^{137}Cs in Australian vegetation. A summary of this information is provided below to enable the reader to make a comparison in a broad sense with the results from this study. It is up to the reader to ascertain the usefulness of such a comparison bearing in mind the differences in the species being analysed and the variation in locales from which the samples have been sourced.

Radium-226

Species or type	Soil (Bq/kg)	Plant (Bq/kg)	Weight basis	Reference
Desert plants	35	2	Fresh	Lowson and Williams (1985)
Melaleuca sp. (bark)	2950	40	Dry	Giles and Evans (1987)
Melaleuca sp. (leaves)	38.1	4.07	Dry	Davy and Conway (1974)
Melaleuca sp. (leaves)	80.1	1.85	Dry	Davy and Conway (1974)
Melaleuca sp. (leaves)	38.9	0.74	Dry	Davy and Conway (1974)
Melaleuca sp. (leaves)	34.2	0.37	Dry	Davy and Conway (1974)
Melaleuca sp. (leaves)	46.7	2.96	Dry	Davy and Conway (1974)
Melaleuca sp. (leaves)	0.185	0.148	Dry	Davy (1975)
Melaleuca sp. (leaves)	0.74	0.74	Dry	Davy (1975)
Melaleuca sp. (leaves)	9.25	3.7	Dry	Davy (1975)
Melaleuca sp. (leaves)	112.48	7.4	Dry	Davy (1975)
Melaleuca sp. (leaves)	18.13	11.1	Dry	Davy (1975)
Melaleuca sp. (leaves)	2950	300	Dry	Giles and Evans (1987)
Melaleuca sp. (wood)	1970	150	Dry	Giles and Evans (1987)
Melaleuca sp. (wood)	2950	30	Dry	Giles and Evans (1987)
Pandanus sp. (leaves)	2950	110	Dry	Giles and Evans (1987)
Pandanus sp. (wood)	2950	60	Dry	Giles and Evans (1987)
Parra grass	1.48	11.1	Dry	Davy (1975)
Parra grass	11.1	25.9	Dry	Davy (1975)
Parra grass	0.74	7.4	Dry	Davy (1975)
Parra grass	2.22	7.4	Dry	Davy (1975)
Parra grass	17.02	3.7	Dry	Davy (1975)
Parra grass	2.22	7.4	Dry	Davy (1975)
Parra grass	4.07	14.8	Dry	Davy (1975)
Parra grass	2.22	11.1	Dry	Davy (1975)
Parra grass	0.74	3.7	Dry	Davy (1975)
Parra grass	1.48	3.7	Dry	Davy (1975)
Sedge grass	5.18	14.8	Dry	Davy (1975)
Sedge grass	1.48	7.4	Dry	Davy (1975)
Sedge grass	0.185	3.7	Dry	Davy (1975)
Sedge grass	112.48	222	Dry	Davy (1975)
Sedge grass	2.22	12.95	Dry	Davy (1975)
Sedge grass	0.74	22.2	Dry	Davy (1975)
Sedge grass	1.85	18.5	Dry	Davy (1975)

Species or type	Soil (Bq/kg)	Plant (Bq/kg)	Weight basis	Reference
Sedge grass	1.11	29.6	Dry	Davy (1975)
Sedge grass	2.22	7.4	Dry	Davy (1975)
Sedge grass	32.19	22.2	Dry	Davy (1975)
Sedge grass	22.57	162.8	Dry	Davy (1975)
Sedge grass	11.84	74	Dry	Davy (1975)
Sedge grass	1.11	22.2	Dry	Davy (1975)
Sedge grass	0.74	3.7	Dry	Davy (1975)
Sedge grass	1.48	11.1	Dry	Davy (1975)
Sedge grass	6.29	74	Dry	Davy (1975)

Caesium-137

Sample	Type	Location	Activity (Bq/kg)		
Avocado		Coffs H.	0.57	+/-	0.17
Avocado		Coffs H.	0.85	+/-	0.46
Banana		Coffs H.	0.40	+/-	0.17
Banana		Noonamah	0.55	+/-	0.49
Lemon	Meyer	Noonamah	0.15	+/-	0.50
Mango		Noonamah	0.33	+/-	0.44
Mung bean	Satin	Lawes	0.06	+/-	0.18
Mung bean	Berken	Pittsworth	0.22	+/-	0.20
Pawpaw		Noonamah	1.25	+/-	0.46
Rambutan		Noonamah	0.70	+/-	0.62
Sorghum		Lawes	0.23	+/-	0.73
Sorghum Aitken A2	Buster	Tamworth	0.41	+/-	0.16
Sorghum Aitken A3	Buster	Tamworth	0.43	+/-	0.14
Sorghum Bowler B1	DeCalb 3GY/DK35	Tamworth	0.17	+/-	0.11

^{137}Cs measurements by John Twining on samples supplied by others

Appendix E5 Radioactivity Analysis Report — Fauna and Water

This appendix gives the results of analyses of water and fauna for the presence of radionuclides.

E5.1 Sample Details

- Twelve animal samples (see Table E5.1) and three water samples (Table E5.2) were analysed for the radionuclides shown in the tables.

E5.2 Analytical Method

Fauna samples were measured by high resolution gamma-ray spectrometry.

For the water samples:

- Gross radioactivity concentrations were determined by ISO methods, ISO 9696 and ISO 9697. Potassium-40 was determined by measurement of stable potassium by atomic absorption spectrometry and calculation using factor 27.6 Bq of 40K beta activity per gram of potassium.
- Radium-226 was determined by liquid scintillation counting after preliminary radiochemical separation of radium. Radium-228, lead-210, caesium-137 and thorium-228 were measured by high resolution gamma-ray spectrometry after pre-concentration of the sample by evaporation.
- Tritium was separated from interfering compounds by distillation of the sample and then measured by liquid scintillation counting of the distilled sample.

TABLE E5.1 Radioactivity analysis report #EA0-242 — fauna analysis (a)

ARPANSA Sample ID	Client sample ID	Sample[(1)] mass (g)	Radioactivity concentration (Bq/kg)							
			^{238}U Series			^{232}Th Series		^{137}Cs	^{60}Co	^{40}K
			^{238}U	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th			
EA01-242-1160a	52a Rabbit carcass (meat)	13	<28	<7	<40	<17	<5	<5	<5	598 ± 57
EA01-242-1160b	52a Rabbit carcass (bones)	13	<24	<7	37 ± 21	<12	<4	<5	<5	310 ± 46
EA01-242-1161	52a Rabbit liver	2.0	<200	<33	<160	<96	<31	<20	<25	420 ± 180
EA01-242-1162	52a Rabbit kidney	0.9	<270	<82	<340	<230	<46	<56	<67	<830
EA01-242-1163	40a Sheep carcass	270	<3	<0.5	<4	<2	<0.4	<27	<38	410 ± 23
EA01-242-1164a	40a Rabbit carcass (meat)	16	<21	<6	<23	<14	<4	<4	<5	350 ± 40
EA01-242-1164b	40a Rabbit carcass (bones)	14	<25	<6	53 ± 21	<19	<5	<4	<5	350 ± 22
EA01-242-1165	40a Rabbit liver	2.1	<190	<30	<160	<85	<19	<19	<23	360 ± 180
EA01-242-1166	40a Rabbit kidney	1.0	<250	<72	<340	<200	<43	<51	<63	<740
EA01-242-1167	40a Sheep liver	21	<18	<5	<3	<13	<4	<3	<4	330 ± 40
EA01-242-1168	40a Sheep kidney	14	<30	<8	<45	<17	<6	<5	<5	410 ± 44
EA01-242-1169	40a Arcoona ants	5.2	68 ± 42	<15	<66	<36	<8	<10	<10	174 ± 77
EA01-242-1170	45a Arcoona ants	6.9	<95	<13	<74	<38	<12	<9	<10	382 ± 84
EA01-242-1171	52a Arcoona ants	5.1	<66	<17	<91	<45	<10	<12	<12	390 ± 110

Results reported on a dry weight basis.
(1) Sample mass used in high resolution gamma-ray spectrometry measurement.

TABLE E5.2 Radioactivity analysis report #EA0-242 — water analysis (b)

ARPANSA sample ID	Client sample ID	Radioactivity concentration (Bq/L)								
		Gross[(1)] alpha	Gross beta[(1)] (uncorrected)	^{40}K beta	^{226}Ra	^{228}Ra[(2)]	^{210}Pb[(2)]	^{228}Th[(2)]	^{137}Cs[(2)]	^{3}H
EA01-242-1212	40a 50SW	<2.4	2.3 ± 0.8	0.88 ± 0.09	0.04 ± 0.01	0.12 ± 0.05	0.80 ± 0.15	<0.02	<0.03	<18
EA01-242-1213	45a 50SW	<2.1	1.8 ± 0.7	1.3 ± 0.1	0.19 ± 0.01	0.27 ± 0.04	<0.21	0.03 ± 0.01	<0.03	<18
EA01-242-1214	52a 50SE	<1.9	1.5 ± 1.0	1.2 ± 0.1	0.20 ± 0.01	0.62 ± 0.05	<0.22	0.07 ± 0.01	<0.03	<18

(1) The limit of detection is dependent on the concentration of dissolved solids in the sample.
The confidence level (2σ) takes into account only the counting uncertainty.
Alpha measurements are ^{241}Am equivalent and beta measurements are ^{40}K equivalent.

(2) Sample measured by high resolution gamma-ray spectrometry after pre-concentration of sample by evaporation.

Appendix E6
Calculation of Radiological Risks to Construction Workers

This appendix supports information presented in Chapter 12 and provides more detail on the assessment of risks to construction workers from naturally occurring radionuclides.

E6.1 Exposure Scenario

The radiation exposures to the trench construction workers arise from the presence of naturally occurring radionuclides in the local soils and rocks. It has been assumed that they will be working in relatively dusty environment and not taking any precautions to prevent inhalation or accidental ingestion of dust. They will incur external radiation doses from the gamma-emitting radionuclides in the soils and internal irradiation form the inhalation and ingestion of dust. The values assumed for working hours, breathing rates and ingestion rates are shown in Table E6.1.

TABLE E6.1 Exposure to excavation workers

Parameter	Symbol	Unit	Value
Time of excavation	T_{excav}	h	200
Rate of dust Ingestion	m	kg/h	1.25E-05
Dust load	μ	kg/m^3	5.0E-06
Breathing rate	B	m^3/h	1.2

The assessment used the higher end of the range of concentrations of ^{238}U, ^{232}Th and ^{40}K found at Site 52a to illustrate the potential radiological implications during construction of the trench (Table E6.2).

TABLE E6.2 Activity used for assessment

Radionuclide	Activity (Bq/kg)
^{238}U	39
^{226}Ra	39
^{210}Pb	46
^{228Th}	57
^{232}Th	51
^{40}K	335
^{137}Cs	5.6

E6.1.1 Effective Dose Equations

The starting point for the calculations of effective dose is the concentration of each radionuclide in the soil, C_i (in Bq/kg) at any time. In the equations that follow, the subscript i representing the radionuclide, is implied.

The equations for the effective dose from external exposure, ingestion and inhalation are given below.

E6.1.2 External Exposure

In this case, the relevant equation is:

$$H_{ext}=T_{excav}H_4C$$

where

H_{ext} (Sv) is the effective dose due to external exposure;
T_{excav} (h) is the time over which exposure occurs during excavation
H_4 (Sv/h) is the effective dose rate (Sv/h) 1 m above an infinite thick slab source of strength 1 Bq/kg
C (Bq/kg) is the radionuclide concentration in the soil.

E6.1.3 Ingestion of Dust

In this case, the relevant equation is:

$$H_{ing} = T_{excav}CmH_2$$

where

H_{ing} (Sv) is the effective dose from ingestion of dust
m (kg/h) is the rate of dust ingestion during excavation
H_2 (Sv/Bq) is the committed effective dose per unit intake by ingestion.

E6.1.4 Inhalation of Dust

In this case, the relevant equation is

$$H_{inh} = T_{excav}C\mu BH_3$$

where

H_{inh} (Sv) is the effective dose from inhalation of dust
μ(kg/m^3) is the dust load in the respiratory zone of the exposed individual
B (m^3/h) is the breathing rate of the exposed individual
H_3 (Sv/Bq) is the committed effective dose per unit intake by inhalation.

The radionuclide data for the dose calculations are given in Table E6.3.

TABLE E6.3 Dose rate conversion factors for excavation scenario[(1)]

Radionuclide	H_4 Effective dose rate at 1m above infinite slab Sv/h per Bq/kg	k_1 External dose rate to an individual on contaminated soil Sv/yr per Bq/kg	H_3 Committed effective dose for inhalation Sv/Bq	H_2 Committed effective dose for ingestion Sv/Bq
^{137}Cs	9.44E-11	8.27E-07	3.9E-08	1.3E-08
^{210}Pb	5.85E-14	5.13E-10	5.6E-06	6.9E-07
^{226}Ra	3.13E-10	2.75E-06	9.5E-06	2.8E-07
^{228}Th	2.12E-13	1.86E-09	4.00E-05	7.20E-08
^{230}Th	3.16E-14	2.77E-10	1.00E-04	2.10E-07
^{232}Th	1.35E-14	1.18E-10	1.10E-04	2.30E-07
^{238}U	2.35 E-15	2.06E-11	8.00E-06	4.50E-08

(1) Committed effective doses for ingestion and inhalation were taken from International Commission on Radiological Protection (1996).
The effective dose rates for an infinite slab and for contaminated soil were taken from International Commission on Radiological Protection (1994).

The results show that the total radiation dose from external and internal irradiation is of the order of 1.8 x 10^{-5} Sv. The most important radionuclides contributing to the dose of the thorium radionuclides, ^{232}Th, ^{230}Th and ^{228}Th. The radiation dose from inhalation of dust is the most significant pathway, and is of the order of 1.5 x 10^{-5} Sv. These doses, as may be expected, are a very small addition to the average annual radiation exposure in Australia, 2 x 10^{-3} Sv/yr. Using a dose to risk conversion factor of 0.06, this is equivalent to the risk of contracting a fatal cancer of 1 in 10^{6}.

E6.2 References

International Commission on Radiological Protection. 1996. Age-dependent doses to members of the public from intake of radionuclides: Part 5 – Compilation of ingestions and inhalation dose coefficients, ICRP Publication 72. Annals of the ICRP, 26(1).

International Commission on Radiological Protection. 1994. Dust coefficients for intakes of radionuclides by workers, ICRP Publication 68. Pergamon Press, Oxford.

Appendix E7
Radiological Risks from Missile or Aircraft Impact

The preferred site for the national repository for low level and short-lived intermediate level radioactive waste is located within the Woomera Prohibited Area (WPA), which is used by the Department of Defence for weapons testing activities. The objective of this appendix is to assess the potential radiological impact arising from the disruption of the repository by activities at the WPA in the near future.

E7.1 Basis for the Assessment

The assessment is based on the best estimate of the total radionuclide inventory (current plus estimated future arisings for the next 50 years). The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) would determine the total radionuclide inventory (both for bulk material and for individual sources) acceptable for disposal at the repository. ARPANSA would take into account the exact location of the site, the detailed repository design and the acceptance and verification of the scenarios and assumptions used in the risk assessments.

E7.2 Radionuclide Inventory

Australia has accumulated about 3700 m^3 of radioactive waste from over 40 years of research, medical and industrial uses of radioactive material. Over half this total is 2010 m^3 of slightly contaminated soil stored near Woomera, which arose from Commonwealth Scientific and Industrial Research Organisation (CSIRO) research into the processing of radioactive ores during the 1950s and 1960s. Another major component is 1320 m^3 of Australian Nuclear Science and Technology Organisation (ANSTO) operational waste, including clothing, paper and glassware, stored at Lucas Heights near Sydney.

The Department of Defence (Defence) has 210 m^3 of waste, including contaminated soils from land remediation, sealed sources, gauges, electron tubes and other equipment, which is held at a number of locations around the country. The remaining waste, approximately 160 m^3, comprises spent sealed sources and miscellaneous laboratory waste from hospitals, universities, industrial activities and other 'small users', and is distributed throughout the country.

Future arisings of waste suitable for disposal at a surface repository are estimated to be about 50 m^3 per year. The decommissioning of the High Flux Australian Reactor (HIFAR) reactor at Lucas Heights could result in the production of 500–2500 m^3 of low-level waste depending on the decommissioning strategy adopted and the timing of the activity. The material arising from the Moata research reactor, which was decommissioned in 1995, is expected to total about 55 m^3.

The total volume of the repository required for disposing of the current waste inventory and that arising over the next 50 years, including appropriate conditioning and packaging has been estimated to be up to about 10,000 m^3.

In the simplified approach adopted in the calculations reported here, it is assumed that the inventory is uniformly distributed throughout the repository. The assumed inventory of radionuclides is shown in Table E7.1.

TABLE E7.1 Assumed inventory for the national repository[(1)]

Radionuclide	Activity level for near-surface disposal (Bq)	Radionuclide	Activity level for near-surface disposal (Bq)
Ac-227	6.53E+08	Ir-192	4.46E+09
Ag-108m	0.00E+00	Kr-85	6.99E+09
Am-241	2.34E+11	Na-22	0.00E+00
Am-241/Be	8.94E+09	Ni-63	4.11E+09
Ba-133	3.79E+08	Np-237	2.18E+08
Be-10	0.00E+00	Pa-231	0.00E+00
Bi-207	2.72E+05	Pb-210	2.87E+07
Bi-214	0.00E+00	Pm-147	2.45E+11
^{14}C	9.69E+05	Po-210	2.87E+07
Cd-109	4.03E+08	Pu-238	0.00E+00
Cf-252	2.04E+08	Pu-239	0.00E+00
Cl-36	0.00E+00	Ra-226	8.13E+10
Cm-244	0.00E+00	Ra-226/Be	1.20E+09
Co-57	0.00E+00	Ru-106	8.71E+08
Co-60	1.15E+12	S-35	0.00E+00
Cs-134	2.49E+08	Sb-124	0.00E+00
Cs-137	1.82E+12	Sb-125	1.72E+09
Eu-152	5.65E+09	Sn-113	0.00E+00
Eu-154	7.60E+08	Sr-90	9.38E+10
Fe-55	1.63E+06	Th-230	2.87E+07
Gd-153	0.00E+00	Th-232	7.51E+09
H-3	1.55E+12	Tl-204	1.63E+09
Ho-166	4.03E+08	U-234	2.87E+07
I-125	0.00E+00	U-235	3.57E+09
I-129	1.61E+06	U-238	1.20E+11

(1) Estimated total radionuclide inventory (current plus estimated future arising for the next 50 years)

E7.3 Proposed Design of the Repository

It is assumed that there is around 10,000 m^3 of waste packages, and that these will be buried in a trench with a cap of thickness 5 m over the top. It is assumed that the dimensions of the trench will be 100×10 m on the ground surface, and so the wastes will occupy a depth of about 10 m. If the cap has thickness 5 m, this means that the wastes will lie 5–15 m below the ground surface.

It is assumed that the wastes are distributed homogeneously throughout the volume of the repository (excluding the cap).

E7.4 Regulatory Context

During the operation of a near-surface repository, the exposures of the repository workers and others can reasonably be predicted, as the times of exposure are known and other controlling factors such as beta and gamma dose rates can be measured. In such situations, where an exposure is actually occurring or is certain to occur, the International Commission on Radiological Protection (ICRP) recommends the use of a dose assessment and associated dose limits as a basis for assessment of the safety of the facility

(International Commission on Radiological Protection 1991). For members of the public, the dose limit is an annual effective dose of 1 mSv above the ambient background dose rate. For occupationally exposed workers, the dose limit is 20 mSv/yr, averaged over a five-year period.

Where exposures are not certain to occur, for example in potential accident scenarios, the ICRP recommends the use of a risk-based assessment and risk limits for assessment of the safety of the facility.

Radiological risk is defined as follows:

$$R = rPH$$

where R (yr^{-1}) is the individual risk
H (Sv) is the effective dose assuming intrusion takes place
r (Sv^{-1}) is the dose to risk conversion factor
P (yr^{-1}) is the probability of exposure in any one year.

It should be noted that this expression, strictly speaking, is only valid for low levels of radiation exposure, where stochastic effects of radiation predominate, as opposed to deterministic effects (i.e. effective doses less than about 0.5 Sv). Risk is normally expressed as an annual probability; the factor *rH* is the probability of inducing a fatal cancer or serious hereditary effect, given that the exposure occurs.

The current position concerning the regulation of near-surface disposals in Australia is set out in two National Health and Medical Research Council (NHMRC) documents (NHMRC 1992, 1997). The following criterion is relevant:

> The exposure of individuals resulting from a combination of all the relevant practices should be subject to dose limits or to some control of risk in the case of potential exposures (individual dose and risk limits). (NHMRC 1992)

The NHMRC (1997) suggests that an effective dose limit of 1 mSv/yr and a risk limit of 5×10^{-5}/yr (for a site in an arid region for which no other potential artificial sources of exposure exist for members of the critical group) should apply, although higher effective doses of 5 mSv/yr may be acceptable if they are restricted to one year. Recent advice from ARPANSA is that the risk limit should be 1×10^{-6}/yr. No time cut-off is specified beyond which the radiological consequences of disposal need not be considered.

In this assessment, radiological doses and risks from accidental human intrusion into the repository were estimated and compared with an effective dose limit of 1 mSv/yr and a risk limit of 1×10^{-6}/yr.

E7.5 Assessment Methodology

The approach taken for the assessment is to initially identify ways in which an individual may become exposed to radiation, and receive a radiation dose. This is termed an ‘exposure scenario’. In this assessment we are solely concerned with risks to users of the Woomera facility in the relatively near future. Therefore we have not addressed the possible evolution of the site in the more distant future, which may potentially arise as a result of climate change or when restricted access to the site is removed.

Having identified an exposure scenario, for example, a missile crash onto the site penetrating the cover material and exposing the waste, we then identify the ‘critical group’. The critical group are those individuals who, by the nature of the lifestyle or occupation, will be most exposed to radiation or radioactive materials in this scenario. The specific habits of the critical group are then defined, for example, exposure times or intake rates.

The doses to the critical groups can then be calculated. The risks to the critical groups of serious health effects are also calculated taking into account the relationship between radiation exposure and health effects and also from the probability of the event described occurring.

The assessment approach is demonstrated in the following example, in which the dose to an individual who is investigating a missile crash at the repository site, but who is unaware that the site is a nuclear repository and has taken no protective measure, might be 5 mSv (5 x 10^{-3} Sv). This may be compared with the annual dose limit for a member of the public of 1 mSv/yr, or for a classified radiation worker of 20 mSv/yr averaged over 5 years (Section 3.2.2).

Using a dose-to-risk conversion factor of 0.06/Sv and this assumed dose, the individual would have a 3 x 10^{-4} (3 in 10,000) chance of incurring a fatal cancer as a result of this exposure. This is approximately equivalent to a risk of serious health effects (National Radiological Protection Board 1992) (typically a fatal cancer or serious hereditary effects), and can be compared to other risk factors for fatalities, such as driving, smoking and obesity.

In addition, we need to consider the probability of this event occurring. If a missile crashes in an uncontrolled manner on the Woomera site, say once a year, then given the proportion of the repository disposal area (100 x 100 m, or 0.01 km^2) to the total WPA (127,800 km^2), the risk of a missile hitting the actual repository itself or within 100 m of it (about 9 times the area of the repository) is 7.0 x 10^{-7} hits per year. Therefore, the overall risk to an individual of incurring a fatal cancer would be (3 x 10^{-4}) x (7.0 x 10^{-7}), which is 2.1 x 10^{-10}/yr, or about a 2 in 10,000,000,000 chance of incurring a fatal cancer from this scenario in a year.

The assessment approach can therefore be summarised in the following steps:

1. Select a number of exposure scenarios.
2. Define the critical group(s) appropriate to each scenario.
3. Define the exposure pathways for each critical group (i.e. the ways in which the critical group is exposed to radiation and radioactive material, e.g. the inhalation of contaminated dust).
4. Define the behaviour of the critical group in terms of exposure times, intake rates, etc.
5. Evaluate doses and risks to the critical groups, and compare them with appropriate target dose and risk values.

The most satisfactory means of selecting a set of scenarios is to use formal methods, such as those in Kelly and Billington (1997). These involve assessment and local experts sitting together and developing ideas based on their knowledge of the proposed disposal site and the way in which the repository and its environs are likely to evolve in time. Such approaches have the benefit of providing a traceable and auditable analysis that can be scrutinised and revised as new knowledge and information becomes available.

In the absence of a formal scenario evaluation exercise, a number of assumptions have been made with respect to possible events at Woomera. Once the exposure scenarios have been defined, it is necessary to determine the critical groups who will suffer the greatest exposures.

There are a number of ways in which critical groups can receive a radiation dose from materials disposed of in the repository. These include:

- external irradiation (from gamma emitting radionuclides)
- inhalation of contaminated dust
- ingestion of contaminated soils and dust.

Once the critical groups have been identified, it is necessary to define their behaviour in terms of parameter values that can be used in dose equations. The two most important quantities are exposure times and intake rates. Thus, to calculate external gamma doses, it is necessary to know the amount of time a critical group member spends in the vicinity of contaminated material. Intake rates are required to calculate internal doses.

Radiological doses and risks are obtained by using the equations set out in Section E7.4 and E7.7. All doses are expressed as effective doses, that is, they take account of the distribution of the radionuclides within the body and of the relatively sensitivity of different organs to radiation effects.

E7.6 Scenarios

After due consideration of the conditions likely to prevail at the Woomera site and from experience with previous near-surface assessments, it was decided that the following exposure scenarios should be considered in this assessment:

- the effects of a missile crash from the nearby Woomera test ranges
- the effects of an aircraft crash (associated with Department of Defence activities at Woomera) onto the repository site.

The term ‘missile’ refers to any type of weapon or projectile used at the site. It also includes satellites and associated propulsion systems. The distinction between ‘missile’ and ‘aircraft’ is generally one of size (the potential for disruption of the repository site) and the length of time for any investigation and recovery operations.

It is not claimed that these scenarios comprise a comprehensive or exhaustive description of possible future happenings at the site. However, these scenarios will broadly scope the range of consequences that might be expected to arise.

E7.6.1 Critical Groups Associated with Scenarios

Each of the scenarios described in the previous section requires the definition of a critical group. In this section, the appropriate critical group is defined, as it is these critical groups that would be expected to receive the highest doses. Each of the scenarios and critical groups are considered in turn below.

Missile Crash

In this scenario, a rocket, missile or satellite crash occurs at the repository site. For the purposes of assessment, it is assumed that the effect of the crash is to penetrate the cap materials, thus exposing the wastes and distributing these over the surrounding area. The critical group is a recovery team which investigates the crash and comes into contact with the radioactive wastes. It is not immediately realised that the impact has occurred on the repository site and therefore no precautions, such as the use of protective equipment or health physics monitoring, are taken by the team.

The crash recovery team comes to the site from outside and leaves the site once their work is done. The exposure pathways for the missile crash are:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides.

Aircraft Crash

In this scenario, an aircraft is assumed to crash at the repository site. The critical group is taken to be the aircraft recovery team who come to investigate the accident and clear up the debris. It is known that the British Royal Air Force (RAF) can take up to two days to clear the debris, and so the exposure time is taken as 25 hours, corresponding to about two 12-hour working days.

It is not immediately realised that the impact has occurred on the repository site and therefore no precautions, such as the use of protective equipment or health physics monitoring, are taken by the team.

The crash recovery team comes to the site from outside and leaves the site once their work is done. The exposure pathways for the aircraft crash are:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides.

These two scenarios are very similar. The main distinction between them is the amount of radioactive material that might be exposed and released to the surface and the probability of the event occurring. These are discussed below.

E7.6.2 Scenario Probabilities

In order to estimate radiological risks, it is necessary to estimate probabilities of occurrence for the scenarios. Usually these are expressed on the basis of an annual probability or frequency of occurrence. Probabilities of this type are dimensionless.

In this section, each of the scenarios is considered in turn.

Missile Crash

According to information supplied by Defence, of the weapons fired on the Woomera test site in the last ten years, about 42 per annum are capable of penetrating to a depth of 5 m. Therefore, it is assumed that about 42 missiles potentially disruptive to the repository hit the ground in the WPA every year.

If it is assumed that these 42 missiles land at random positions on the test site (an assumption that may not be valid, if the missiles are fired within a limited range of trajectory and velocity values), then an estimate of frequency of impact on the repository can be made. The total area of the Woomera test site is 127,800 km^2 and the repository has a cross-sectional area of 0.01 km^2. If it is further assumed that any strike within 100 m of the repository causes disruption to the wastes, i.e. approximately 9 times the repository disposal area, then the frequency of strike is approximately:

$$f(\text{missile}) = (42 \times 9 \times 10^{-2}) \div (1.28 \text{ x } 10^{5}) = 3.0 \text{ x } 10^{-5} \text{ disruptions per year}$$

Aircraft Crash

The probability of an aircraft crash into the repository can be estimated from consideration of aircraft crash data. According to Defence, one aircraft crash has occurred at the Woomera test site over the last 10 years.

As with the missile crashes, the best way to proceed is to assume that aircraft crashes occur at random locations on the test site. The target area for which a crash can disturb the repository wastes will be taken to be the same as that for missiles; that is, any impact within 100 m of the repository location, i.e. approximately 9 times the repository disposal area, will be considered to disturb the wastes.

From this, the frequency of a disruptive aircraft impact is approximately:

$$f(\text{aircraft}) = (0.1 \text{ x } 9 \text{ x } 10^{-2}) \div (1.28 \text{ x } 10^{5}) = 7.0 \text{ x } 10^{-8} \text{ crashes per year}$$

E7.7 Radiological Dose Equations

In this section, equations are presented for evaluating radiological doses via the various exposure pathways identified for each scenario in Section E7.6. The basis of the dose equations are very simple. For external doses, the form of the dose equations are:

Effective dose rate (Sv/yr) = *Gamma dose rate* (Sv/hr) × *Exposure time* (hr/yr)

For internal doses, the corresponding expression is:

Effective dose rate (Sv/yr) = *Intake per unit time* (Bq/yr) × *Dose-per-unit-uptake* (Sv/Bq)

The starting point for the dose calculations is the calculation of radionuclide concentrations in the repository. In the homogeneous model (i.e. the radionuclides are assumed to be distributed uniformly throughout the repository volume), the concentration is simply the radionuclide inventory divided by the mass of repository materials:

$$C_i = \frac{M_i}{\rho V}$$

where C_i (Bq/kg) is the mass concentration of radionuclide *i*
M_i (Bq) is the current inventory of radionuclide *i*
ρ (kg/m^3) is density of repository materials
V (m^3) is volume of repository materials.

To calculate concentrations as a function of time, the inventory is decayed forwards in time using Bateman's equations and their solution:

$$\frac{dN_i}{dt} = \lambda_i (N_{i-1} - N_i) ,$$

where N_i (Bq) is the activity of radionuclide *i*
λ_i (yr^{-1}) is the decay constant of radionuclide *i*
t (yr) is the time under consideration.

The equations are written in terms of activity units (Becquerels). The calculation of concentrations requires a knowledge of the repository dimensions and material properties, the radionuclide inventory and the radionuclide half-lives. These are given in Tables E7.3, E7.1 and E7.2, respectively. Table E7.2 contains the radionuclide-specific parameter values that are used in this assessment.

For reference, the parameter values used in these equations to undertake the dose and risk assessments for the critical groups are set out in tables, as follows:

- Table E7.1 Proposed inventory for the national repository
- Table E7.2 Radionuclide-specific parameter values
- Table E7.3 Design parameters for the national repository
- Table E7.4 Parameter values for the missile crash scenario
- Table E7.5 Parameter values for the aircraft crash scenario.

Dose-per-unit-uptake factors were obtained from ICRP 72 (International Commission on Radiological Protection 1996), and, where required, basic human physiological data was obtained from ICRP 23 (International Commission on Radiological Protection 1975).

The following subsection provides dose equations for each of the scenarios considered.

E7.7.1 Missile and Aircraft Crashes

In this subsection, the calculation of the doses received by the workers undertaking recovery operations are described. With appropriate data, the model described below is applicable to both the missile and aircraft crash scenarios.

In this case, consideration has to be given to external exposure, ingestion of dust and inhalation of dust.

TABLE E7.2 Radionuclide-specific parameter values

Nuclide	$T_{0.5}$	H_1	H_2	H_3	H_4
H-3	1.24E+01	0.00E+00	1.80E-11	1.80E-11	0.00E+00
^{14}C	5.73E+03	0.00E+00	6.50E-12	5.80E-10	5.88E-23
Sr-90	2.91E+01	1.58E-19	1.60E-07	2.80E-08	3.46E-21
Fe-55	2.70E+00	1.58E-16	7.70E-10	3.30E-10	0.00E+00
Co-60	5.27E+00	2.50E-13	3.10E-08	3.40E-09	8.25E-17
Ni-63	9.60E+01	0.00E+00	1.30E-09	1.50E-10	0.00E+00
Cd-109	1.27E+00	0.00E+00	8.10E-09	2.00E-09	6.54E-20
Sb-125	2.77E+00	0.00E+00	1.20E-08	1.10E-09	1.22E-17
I-129	1.57E+07	2.30E-15	3.60E-08	1.10E-07	5.11E-20
Ba-133	1.07E+01	0.00E+00	1.00E-08	1.50E-09	9.75E-18
Cs-134	2.06E+00	0.00E+00	2.00E-08	1.90E-08	4.77E-17
Cs-137	3.00E+01	6.79E-14	3.90E-08	1.30E-08	1.71E-17
Pm-147	2.62E+00	0.00E+00	5.00E-09	2.60E-10	2.30E-22
Eu-152	1.33E+01	1.25E-13	4.20E-08	1.40E-09	3.50E-17
Eu-154	8.80E+00	1.34E-13	5.30E-08	2.00E-09	3.89E-17
Eu-155	4.96E+00	0.00E+00	6.90E-09	3.20E-10	8.66E-19
Tl-204	3.78E+00	0.00E+00	3.90E-09	1.20E-09	2.08E-20
Bi-207	3.80E+01	0.00E+00	5.60E-09	1.30E-09	4.73E-17
Po-210	3.79E-01	1.03E-18	4.30E-06	1.20E-06	2.64E-22
Pb-210	2.23E+01	4.49E-16	5.60E-06	6.90E-07	1.06E-20
Ra-226	1.60E+03	1.83E-13	9.50E-06	2.80E-07	5.68E-17
Ra-228	5.75E+00	1.06E-13	1.60E-05	6.90E-07	3.03E-17
Ac-227	2.18E+01	4.67E-14	5.50E-04	1.10E-06	1.58E-20
Th-228	1.91E+00	1.50E-13	4.00E-05	7.20E-08	3.84E-20
Th-229	7.34E+03	3.71E-14	2.40E-04	4.90E-07	1.55E-18
Th-230	7.70E+04	1.48E-16	1.00E-04	2.10E-07	5.73E-21
Th-232	1.41E+10	1.25E-16	1.10E-04	2.30E-07	2.44E-21
Pa-231	3.28E+04	5.52E-15	1.40E-04	7.10E-07	9.44E-19
U-233	1.59E+05	1.27E-16	9.60E-06	5.10E-08	6.77E-21
U-234	2.45E+05	1.62E-16	9.40E-06	4.90E-08	1.84E-21
U-235	7.04E+08	1.88E-14	8.50E-06	4.70E-08	3.53E-18
U-236	2.34E+07	1.46E-16	8.70E-06	4.70E-08	9.51E-22
U-238	4.47E+09	2.93E-15	8.00E-06	4.50E-08	4.26E-22
Np-237	2.14E+06	2.73E-14	5.00E-05	1.10E-07	3.72E-19
Am-241	4.32E+02	3.03E-15	9.60E-05	2.00E-07	1.99E-19
Cm-244	1.81E+01	0.00E+00	5.70E-05	1.20E-07	4.79E-22

$T_{0.5}$ = radionuclide half life (yr)
H_1 = external dose rate (Sv/h) at 1 m from a point source of 1 Bq
H_2 = committed effective dose per unit uptake by inhalation (Sv/Bq)
H_3 = committed effective dose per unit uptake by ingestion (Sv/Bq)
H_4 = external dose rate (Sv/h) from an infinite plane 1 m above an infinite thick slab source of strength 1 Bq/kg

TABLE E7.3 Design parameters for the repository

Quantity	Units	Value
Repository volume	m^3	1.00E+04
Density of wastes	kg/m^3	1.50E+03
Porosity of wastes	–	3.00E-01
Depth of wastes	m	1.00E+01
Repository cross section	m^2	1.00E+03
Cap thickness	m	5.00E+00
Spoil density	kg/m^3	1.50E+03
Spoil porosity	–	3.00E-01

TABLE E7.4 Parameter values for the missile crash scenario

Parameter	Symbol	Units	Value
Dilution factor(1)	*f*		1.00E+00
Time of exposure(2)	T_{exp}	h	1.00E+01
Rate of dust ingestion	*m*	kg/h	1.25E-05
Dust load(3)	μ	kg/m^3	1.00E-06
Breathing rate(4)	*B*	m^3/h	1.20E+00

(1) The dilution factor was chosen under the assumption that the recovery team might be exposed to the radioactive wastes directly without any dilution from other materials. A variation was also assessed assuming that the radioactive waste would be diluted with the cover material, *f* = 0.66.
(2) The time of exposure was set on the assumption that there would be fewer components to recover compared to the aircraft recovery exercise.
(3) The dust load is appropriate to a moderately dusty environment.
(4) The breathing rate is appropriate to moderate physical activity.

TABLE E7.5 Parameter values for the aircraft crash scenario

Parameter	Symbol	Units	Value
Dilution factor(1)	*f*		1.00E+00
Time of exposure(2)	T_{exp}	h	25
Rate of dust ingestion	*m*	kg/h	1.25E-05
Dust load(3)	μ	kg/m^3	1.00E-06
Breathing rate(4)	*B*	m^3/h	1.20E+00

(1) The dilution factor was chosen under the assumption that the recovery team might be exposed to the radioactive wastes directly without any dilution from other materials. A variation was also assessed assuming that the radioactive waste would be diluted with the cover material, *f* = 0.66.
(2) The time of exposure was set on the assumption that recovery workers require 25 hours to complete clean-up activities.
(3) The dust load is appropriate to a moderately dusty environment.
(4) The breathing rate is appropriate to moderate physical activity.

The concentration in the excavated materials may be less than the concentration in the disposal structures, however, because of mixing with uncontaminated material also excavated. This is represented by an equation of the form of equation 1.

$$S=fC \tag{1}$$

where S (Bq/kg) is the concentration in the sample
f is the degree of mixing (between 0 and 1)
C (Bq/kg) is the concentration of radionuclides in the waste.

External Exposure

In this case, the relevant equation is:

$$H_{ext}=T_{excav}H_4S \tag{2}$$

where H_{ext} (Sv) is the effective dose due to external exposure
T_{excav} (h) is the time over which contaminated material is exposed during excavation
H_4 is the effective dose rate (Sv/h) 1 m above an infinite thick slab source of strength 1 Bq/kg
S (Bq/kg) is the radionuclide concentration in the sample.

Ingestion of Dust

In this case, the relevant equation is:

$$H_{ing}=T_{excav}SmH_2 \tag{3}$$

where H_{ing} (Sv) is the effective dose from ingestion of contaminated dust
m (kg/h) is the rate of dust ingestion during excavation
H_2 (Sv/Bq) is the committed effective dose per unit intake by ingestion.

Inhalation of Dust

In this case, the relevant equation is

$$H_{inh}=T_{excav}S\mu BH_3 \tag{4}$$

where H_{inh} (Sv) is the effective dose from inhalation of contaminated dust
μ (kg/m^3) is the dust load in the respiratory zone of the exposed individual arising from the contaminated sample
B (m^3 /h) is the breathing rate of the exposed individual
H_3 (Sv /Bq) is the committed effective dose per unit intake by inhalation.

E7.8 Estimated Radiological Doses for Critical Groups

In this section, the results of the dose and risk assessment are set out for the critical groups. The results are presented in a set of tables, as follows:

- Tables E7.6 and E7.7 Doses and risks to the recovery team following the missile crash
- Tables E7.8 and E7.9 Doses and risks to the recovery team following an aircraft crash.

Each table presents the results as a function of exposure pathway (i.e. summed over all radionuclides), along with the maximum individual contribution to the dose from a particular pathway, and the radionuclide that makes that contribution. Total effective dose, conditional risk and annual individual risk are also presented.

TABLE E7.6 Doses (Sv) and risks to the recovery team following a missile crash

Dilution factor, f = 0.66

	External			Inhalation			Ingestion			Total dose			Risks	
Time (y)	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional(1)**	**Annual(2)**
0	2.43E-03	1.83E-03	Co-60	1.15E-05	1.03E-05	Am-241	4.13E-07	2.24E-07	Am-241	2.45E-03	1.83E-03	Co-60	1.47E-04	3.53E-09
1	2.19E-03	1.60E-03	Co-60	1.15E-05	1.03E-05	Am-241	4.06E-07	2.23E-07	Am-241	2.21E-03	1.60E-03	Co-60	1.33E-04	3.18E-09
2	1.98E-03	1.41E-03	Co-60	1.14E-05	1.03E-05	Am-241	4.00E-07	2.23E-07	Am-241	1.99E-03	1.41E-03	Co-60	1.19E-04	2.87E-09
3	1.80E-03	1.23E-03	Co-60	1.14E-05	1.03E-05	Am-241	3.94E-07	2.23E-07	Am-241	1.81E-03	1.23E-03	Co-60	1.09E-04	2.61E-09
5	1.48E-03	9.46E-04	Co-60	1.13E-05	1.02E-05	Am-241	3.84E-07	2.22E-07	Am-241	1.50E-03	9.46E-04	Co-60	9.00E-05	2.16E-09
10	9.68E-04	4.89E-04	Co-60	1.11E-05	1.02E-05	Am-241	3.64E-07	2.20E-07	Am-241	9.80E-04	4.89E-04	Co-60	5.88E-05	1.41E-09
20	5.11E-04	3.80E-04	Cs-137	1.09E-05	9.99E-06	Am-241	3.35E-07	2.17E-07	Am-241	5.23E-04	3.80E-04	Cs-137	3.14E-05	7.53E-10
30	3.37E-04	3.01E-04	Cs-137	1.07E-05	9.83E-06	Am-241	3.13E-07	2.13E-07	Am-241	3.48E-04	3.01E-04	Cs-137	2.09E-05	5.01E-10
50	1.93E-04	1.90E-04	Cs-137	1.04E-05	9.52E-06	Am-241	2.82E-07	2.07E-07	Am-241	2.04E-04	1.90E-04	Cs-137	1.22E-05	2.94E-10
100	6.08E-05	5.98E-05	Cs-137	9.64E-06	8.79E-06	Am-241	2.38E-07	1.91E-07	Am-241	7.07E-05	5.98E-05	Cs-137	4.24E-06	1.02E-10
200	6.84E-06	5.94E-06	Cs-137	8.33E-06	7.49E-06	Am-241	1.99E-07	1.63E-07	Am-241	1.54E-05	7.49E-06	Am-241	9.24E-07	2.22E-11

(1) The conditional risk is the exposure (dose) times the dose-to-risk conversion factor of 0.06 and is the risk of incurring a fatal cancer or serious hereditary defect should the exposure occur.
(2) The annual risk is the conditional risk times the probability of the exposure occurring in a year and is the overall risk of incurring a fatal cancer or serious hereditary defect in a year.
RN = radionuclide

TABLE E7.7 Doses (Sv) and risks to the recovery team following a missile crash

Dilution factor, f = 1

	External			Inhalation			Ingestion			Total dose			Risks	
Time (y)	Dose	Max	RN	Dose	Max	RN	Dose	Max	RN	Dose	Max	RN	Conditional(1)	Annual(2)
0	3.69E-03	2.77E-03	Co-60	1.75E-05	1.56E-05	Am-241	6.26E-07	3.39E-07	Am-241	3.71E-03	2.77E-03	Co-60	2.23E-04	5.34E-09
1	3.32E-03	2.43E-03	Co-60	1.74E-05	1.56E-05	Am-241	6.16E-07	3.39E-07	Am-241	3.34E-03	2.43E-03	Co-60	2.00E-04	4.81E-09
2	3.00E-03	2.13E-03	Co-60	1.73E-05	1.56E-05	Am-241	6.06E-07	3.38E-07	Am-241	3.02E-03	2.13E-03	Co-60	1.81E-04	4.35E-09
3	2.72E-03	1.87E-03	Co-60	1.72E-05	1.56E-05	Am-241	5.98E-07	3.38E-07	Am-241	2.74E-03	1.87E-03	Co-60	1.64E-04	3.95E-09
5	2.25E-03	1.43E-03	Co-60	1.71E-05	1.55E-05	Am-241	5.82E-07	3.36E-07	Am-241	2.27E-03	1.43E-03	Co-60	1.36E-04	3.27E-09
10	1.47E-03	7.40E-04	Co-60	1.69E-05	1.54E-05	Am-241	5.51E-07	3.34E-07	Am-241	1.48E-03	7.40E-04	Co-60	8.88E-05	2.13E-09
20	7.75E-04	5.75E-04	Cs-137	1.66E-05	1.51E-05	Am-241	5.07E-07	3.28E-07	Am-241	7.92E-04	5.75E-04	Cs-137	4.75E-05	1.14E-09
30	5.11E-04	4.57E-04	Cs-137	1.63E-05	1.49E-05	Am-241	4.74E-07	3.23E-07	Am-241	5.28E-04	4.57E-04	Cs-137	3.17E-05	7.60E-10
50	2.93E-04	2.88E-04	Cs-137	1.58E-05	1.44E-05	Am-241	4.27E-07	3.13E-07	Am-241	3.09E-04	2.88E-04	Cs-137	1.85E-05	4.45E-10
100	9.22E-05	9.07E-05	Cs-137	1.46E-05	1.33E-05	Am-241	3.61E-07	2.89E-07	Am-241	1.07E-04	9.07E-05	Cs-137	6.42E-06	1.54E-10
200	1.04E-05	9.00E-06	Cs-137	1.26E-05	1.13E-05	Am-241	3.01E-07	2.46E-07	Am-241	2.33E-05	1.13E-05	Am-241	1.40E-06	3.36E-11

(1) The conditional risk is the exposure (dose) times the dose to risk conversion factor of 0.06 and is the risk of incurring a fatal cancer or serious hereditary defect should the exposure occur.
(2) The annual risk is the conditional risk times the probability of the exposure occurring in a year and is the overall risk of incurring a fatal cancer or serious hereditary defect in a year.
RN = radionuclide

TABLE E7.8 Doses (Sv) and risks to a recovery team following an aircraft crash

Dilution factor, f = 1

	External			Inhalation			Ingestion			Total dose			Risks	
Time (y)	Dose	Max	RN	Dose	Max	RN	Dose	Max	RN	Dose	Max	RN	Conditional(1)	Annual(2)
0	9.22E-03	6.93E-03	Co-60	4.37E-05	3.91E-05	Am-241	1.57E-06	8.48E-07	Am-241	9.27E-03	6.93E-03	Co-60	5.56E-04	5.56E-11
1	8.31E-03	6.07E-03	Co-60	4.34E-05	3.90E-05	Am-241	1.54E-06	8.46E-07	Am-241	8.36E-03	6.07E-03	Co-60	5.02E-04	5.02E-11
2	7.51E-03	5.32E-03	Co-60	4.32E-05	3.89E-05	Am-241	1.52E-06	8.45E-07	Am-241	7.55E-03	5.32E-03	Co-60	4.53E-04	4.53E-11
3	6.80E-03	4.66E-03	Co-60	4.30E-05	3.89E-05	Am-241	1.49E-06	8.44E-07	Am-241	6.84E-03	4.66E-03	Co-60	4.10E-04	4.10E-11
5	5.62E-03	3.58E-03	Co-60	4.27E-05	3.88E-05	Am-241	1.46E-06	8.41E-07	Am-241	5.67E-03	3.58E-03	Co-60	3.40E-04	3.40E-11
10	3.67E-03	1.85E-03	Co-60	4.22E-05	3.84E-05	Am-241	1.38E-06	8.34E-07	Am-241	3.71E-03	1.85E-03	Co-60	2.23E-04	2.23E-11
20	1.94E-03	1.44E-03	Cs-137	4.14E-05	3.78E-05	Am-241	1.27E-06	8.21E-07	Am-241	1.98E-03	1.44E-03	Cs-137	1.19E-04	1.19E-11
30	1.28E-03	1.14E-03	Cs-137	4.07E-05	3.72E-05	Am-241	1.19E-06	8.08E-07	Am-241	1.32E-03	1.14E-03	Cs-137	7.92E-05	7.92E-12
50	7.33E-04	7.19E-04	Cs-137	3.94E-05	3.61E-05	Am-241	1.07E-06	7.83E-07	Am-241	7.73E-04	7.19E-04	Cs-137	4.64E-05	4.64E-12
100	2.30E-04	2.27E-04	Cs-137	3.65E-05	3.33E-05	Am-241	9.02E-07	7.22E-07	Am-241	2.68E-04	2.27E-04	Cs-137	1.61E-05	1.61E-12
200	2.59E-05	2.25E-05	Cs-137	3.15E-05	2.84E-05	Am-241	7.53E-07	6.16E-07	Am-241	5.82E-05	2.84E-05	Am-241	3.49E-06	3.49E-13

(1) The conditional risk is the exposure (dose) times the dose to risk conversion factor of 0.06 and is the risk of incurring a fatal cancer or serious hereditary defect should the exposure occur.
(2) The annual risk is the conditional risk times the probability of the exposure occurring in a year and is the overall risk of incurring a fatal cancer or serious hereditary defect in a year.
RN = radionuclide

TABLE E7.9 Doses (Sv) and risks to a recovery team following an aircraft crash

Dilution factor, f = 0.66

	External			Inhalation			Ingestion			Total dose			Risks	
Time (y)	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional(1)**	**Annual(2)**
0	6.09E-03	4.57E-03	Co-60	2.88E-05	2.58E-05	Am-241	1.03E-06	5.60E-07	Am-241	6.12E-03	4.57E-03	Co-60	3.67E-04	3.67E-11
1	5.49E-03	4.01E-03	Co-60	2.87E-05	2.57E-05	Am-241	1.02E-06	5.59E-07	Am-241	5.51E-03	4.01E-03	Co-60	3.31E-04	3.31E-11
2	4.96E-03	3.51E-03	Co-60	2.85E-05	2.57E-05	Am-241	1.00E-06	5.58E-07	Am-241	4.99E-03	3.51E-03	Co-60	2.99E-04	2.99E-11
3	4.49E-03	3.08E-03	Co-60	2.84E-05	2.57E-05	Am-241	9.86E-07	5.57E-07	Am-241	4.52E-03	3.08E-03	Co-60	2.71E-04	2.71E-11
5	3.71E-03	2.36E-03	Co-60	2.82E-05	2.56E-05	Am-241	9.61E-07	5.55E-07	Am-241	3.74E-03	2.36E-03	Co-60	2.24E-04	2.24E-11
10	2.42E-03	1.22E-03	Co-60	2.79E-05	2.54E-05	Am-241	9.10E-07	5.51E-07	Am-241	2.45E-03	1.22E-03	Co-60	1.47E-04	1.47E-11
20	1.28E-03	9.49E-04	Cs-137	2.73E-05	2.50E-05	Am-241	8.37E-07	5.42E-07	Am-241	1.31E-03	9.49E-04	Cs-137	7.86E-05	7.86E-12
30	8.44E-04	7.54E-04	Cs-137	2.69E-05	2.46E-05	Am-241	7.83E-07	5.33E-07	Am-241	8.71E-04	7.54E-04	Cs-137	5.23E-05	5.23E-12
50	4.84E-04	4.75E-04	Cs-137	2.60E-05	2.38E-05	Am-241	7.05E-07	5.17E-07	Am-241	5.10E-04	4.75E-04	Cs-137	3.06E-05	3.06E-12
100	1.52E-04	1.50E-04	Cs-137	2.41E-05	2.20E-05	Am-241	5.96E-07	4.77E-07	Am-241	1.77E-04	1.50E-04	Cs-137	1.06E-05	1.06E-12
200	1.71E-05	1.48E-05	Cs-137	2.08E-05	1.87E-05	Am-241	4.97E-07	4.06E-07	Am-241	3.84E-05	1.87E-05	Am-241	2.30E-06	2.30E-13

(1) The conditional risk is the exposure (dose) times the dose to risk conversion factor of 0.06 and is the risk of incurring a fatal cancer or serious hereditary defect should the exposure occur.
(2) The annual risk is the conditional risk times the probability of the exposure occurring in a year and is the overall risk of incurring a fatal cancer or serious hereditary defect in a year.
RN = radionuclide

E7.8.1 Missile Crash

For the recovery team who are exposed to the radioactive wastes after a missile crash at the repository site, the maximum doses would be attained if the crash occurred immediately after the repository was filled. This would mean that the inventory was at the maximum value and little radioactive decay had occurred. For simplicity, we have assumed that the repository is filled with the entire inventory (expected over 50 years) in year zero. This is a conservative assumption as we might expect significant decay of ^{60}Co (half-life of 5 years) over the 50 year operating period.

We have also considered two cases, one where the wastes are exposed and unmixed with any cover material, i.e. dilution is zero. The second case assumes that the radioactive wastes are diluted with the cover material, a dilution factor of 0.66.

Case 1: No dilution

For this case the dose is around 3.8×10^{-3} Sv, with the most significant radionuclides being ^{241}Am, ^{137}Cs, and ^{60}Co. External irradiation is the most significant exposure pathway, with ^{60}Co and ^{137}Cs being the most significant contributors. Inhalation of contaminated dust (^{241}Am) is the next most significant exposure pathway.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of missile crashes, the annual individual risk is around 6.9×10^{-9}/yr for a missile crash immediately after the repository is full. This risk value is comfortably below the risk target of 1×10^{-6}/yr.

Thus, even though the assessed dose is slightly in excess of that specified as the public dose limit by many authorities, the low probability of occurrence ensures that the individual risks are small. In fact, in the case of the missile crash, the true frequency of occurrence is likely to be considerably less than the value of 3×10^{-5}/yr assumed in this study.

Case 2: Dilution of radioactive wastes with cover material

For this case the dose is slightly lower at around 2.5×10^{-3} Sv, with the most significant radionuclides being ^{241}Am, ^{137}Cs, and ^{60}Co. External irradiation is the most significant exposure pathway, with ^{60}Co and ^{137}Cs again being the most significant contributors. Inhalation of contaminated dust (^{241}Am) is the next most significant exposure pathway.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of missile crashes, the annual individual risk is around 4.6×10^{-9}/yr for a missile crash immediately after the repository is full. This risk value is comfortably below the risk target of 1×10^{-6}/yr. Thus, even though the assessed dose is slightly in excess of that specified as the public dose limit by many authorities, the low probability of occurrence ensures that the individual risks are small. In fact, in the case of the missile crash, the true frequency of occurrence is likely to be considerably less than the value of 3×10^{-5}/yr assumed in this study.

E7.8.2 Aircraft Crash

Case 1: No dilution

For the aircraft recovery team that clears up aircraft debris lying on exposed wastes after an aircraft crash, the maximum doses would be attained if the crash occurred immediately after the repository is filled. This dose is around 9.6×10^{-3} Sv and therefore higher than that associated with the missile crash due to the longer exposure time assumed for the recovery team. External irradiation is the most significant exposure pathway, with ^{60}Co and ^{137}Cs being the most significant contributor. Inhalation of contaminated dust (^{241}Am) is the next most significant exposure pathway.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of aircraft crashes, the annual individual risk is around 4.0×10^{-11}/yr for an aircraft crash immediately after the end of the period of institutional control. Thus, even though the assessed dose is in excess of that specified as the public dose limit by many authorities, the low probability of occurrence ensures that the individual risks are small. This risk is higher than that associated with the missile crash as the frequency of aircraft crashes was assigned a higher probability. This risk value is comfortably below the risk target of 1 x 10^{-6}/yr.

Case 2: Dilution of radioactive wastes with cover material

For the aircraft recovery team that clears up aircraft debris lying on exposed wastes after an aircraft crash, the maximum doses would be attained if the crash occurred immediately after the repository is filled. This dose is around 6.3 x 10^{-3} Sv. External irradiation is the most significant exposure pathway, with ^{60}Co and ^{137}Cs being the most significant contributors. Inhalation of contaminated dust (^{241}Am) is the next most significant exposure pathway.

Taking into account the dose-to-risk conversion factor of 0.06 /Sv and the frequency of occurrence of aircraft crashes, the annual individual risk is around 2.7 x 10^{-11}/yr for an aircraft crash immediately after the end of the period of institutional control. Thus, even though the assessed dose is slightly in excess of that specified as the public dose limit by many authorities, the low probability of occurrence ensures that the individual risks are small. This risk value is comfortably below the risk target of 1 x 10^{-6}/yr.

E7.9 Conclusions

This assessment of radiological risk from the Department of Defence, and other user activities at Woomera has shown that the risk of serious health effects associated with disturbance of repository material and subsequent investigation is very low and less than the risk target proposed for the repository. The associated risks range from 2.7 x 10^{-11}/yr to 6.9 x 10^{-9}/yr for the scenarios considered as shown in Table E7.10. These risks are also less than the 1 x 10^{-6} required for the safety template at the WPA. This would imply that the presence of an unmanned repository at Site 52a would not restrict the use of the site by Defence or any other user.

TABLE E7.10 Summary of peak doses and risks

Scenario	Critical group	Peak dose(1) (Sv)	Peak risk(2)	Time(3)	Key nuclides
Missile crash No dilution	Missile recovery team	3.71 x 10^{-3}	5.34 x 10^{-8}	0	^{60}Co / ^{137}Cs
Missile crash Dilution of radioactive wastes	Missile recovery team	2.45 x 10^{-3}	3.53 x 10^{-9}	0	^{60}Co / ^{137}Cs
Aircraft crash No dilution	Aircraft recovery team	9.27 x 10^{-3}	5.56 x 10^{-11}	0	^{60}Co / ^{137}Cs
Aircraft crash Dilution of radioactive wastes	Aircraft recovery team	6.12 x 10^{-3}	3.67 x 10^{-11}	0	^{60}Co / ^{137}Cs

(1) Doses are effective doses.
(2) Risks are individual annual risks.
(3) Times are measured in years post-closure.

The assessment made a number of conservative assumptions. It was assumed in the calculation that the full radionuclide inventory predicted to arise over 50 years was present at year 0 and that no radioactive decay had taken place before the exposure occurred.

Very importantly, it was also assumed that the critical group would take no protective measures when investigating an incident at the repository. This might arise through inadequate markings to indicate the presence of the repository, the destruction of these in the incident or from confusion within the recovery team.

The maximum potential dose should an exposure occur is of the order of a few mSv. This is less than the annual dose limit for a classified radiation worker (20 mSv) and represents a risk of contracting a fatal cancer of about 5 in 10^4. There is a lot of conservatism in the assumptions used for the calculations as outlined below.

E7.9.1 Inventory

It is assumed that all of the potential inventory is present at year 0.

The current radionuclide inventory represents the country's use of radioactive material during the past 70–80 years. Future arisings will be limited to small-scale operational and decommissioning arisings. Future radioactive waste arisings over the next 50 years are estimated to be more than twice the current inventory. Therefore a realistic inventory for the early years of the repository would be about 50% of our assumption.

E7.9.2 Effect of Impact on Repository

It is assumed that an impact removes cover and exposes wastes, and mixes waste with cover material only.

This is very much a worst case scenario. It is more likely that the impact crater would mix the radioactive and inert materials to a degree and disperse these over the surrounding area. This would result in a reasonable level of dilution of the radioactive material. It is also possible that the impact might not disturb the radioactive contents at all as the cover depth is 5 m.

E7.10 References

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Appendix E8
Post Institutional Control Risk Assessment

This appendix provides a preliminary, post-institutional control radiological assessment of the proposed repository.

E8.1 Introduction

This assessment may be used to provide a general indication of the radiation doses and corresponding risks that might arise and to highlight key issues. It does not provide a final view on the safety of the proposed facility, which will require further data on the specific disposal trench/borehole design. Full data on the repository site are not yet available and a very simple approach to estimating radiological consequences has been adopted. A number of simplifying assumptions have also been required, for example relating to the assumed frequencies of intrusion events.

A number of scenarios for the future evolution (post-institutional control) of the repository and its environs are considered, including the potential effects of human intrusion, natural disruptive events, migration of gas out of the repository, and transport in groundwater (see Figure E8.1). However, as the proposed facility is to be located in a dry and arid region of Australia, the groundwater pathway is expected to be only of limited significance. Human intrusion, natural disruptive events and the gas pathway are expected to be the main sources of exposure for the general public.

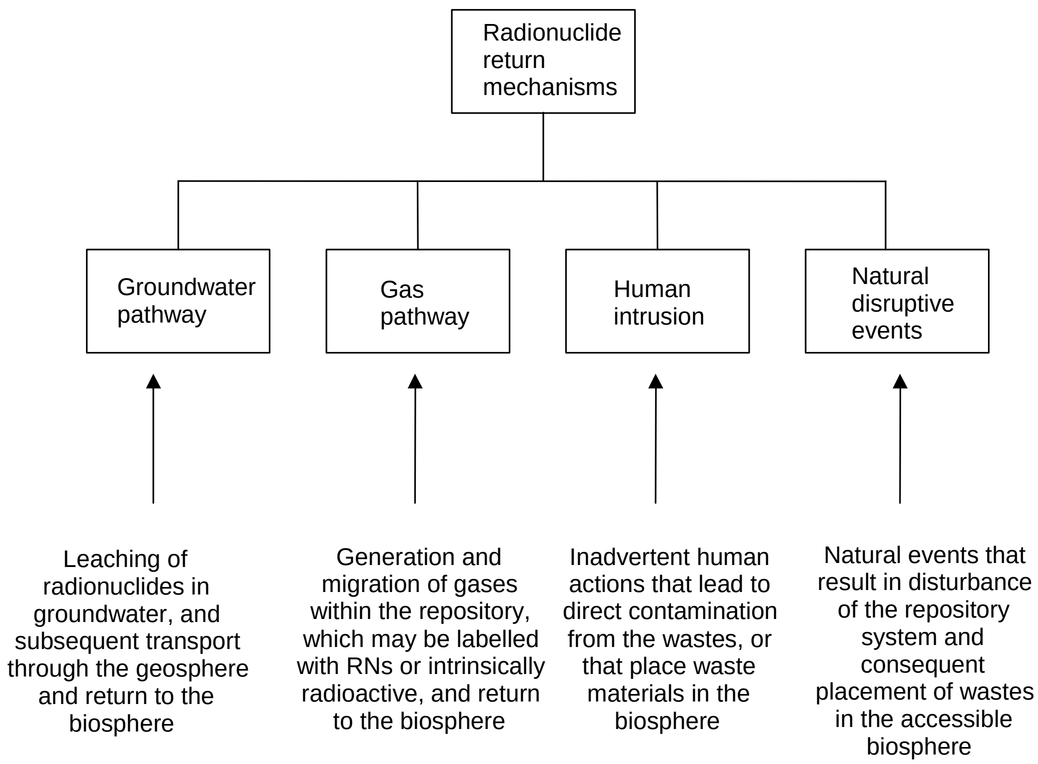

FIGURE E8.1
The four key radionuclide transport mechanisms

The human intrusion scenarios will include the effects of waste drilling and excavation, and also the impact of an aircraft crashing into the repository, the impact of a weapon or rocket crash from the nearby Woomera test site. Natural disruptive events include gross erosion (due to wind and rain action), the onset of a wetter climate and the effects of site flooding under the assumption of a wetter climate. The principal effect of gas migration arises if a house is built on top of the repository. Radioactive gases can accumulate in the house and, if inhaled, can lead to a radiological dose being incurred by the inhabitants. Radon-222 and its progeny is expected to be the principal hazard in this scenario.

The only groundwater transport scenario considered is the potential effects of radionuclides leaching in groundwater through the unsaturated zone and towards the underlying aquifer. Radionuclides could potentially enter the aquifer, and result in contamination of local groundwater supplies. Leaching and transport in near-surface groundwater is not considered.

These scenarios have largely been selected on the basis of general experience in the assessment of near-surface facilities for the disposal of low-level waste, though a graphical technique has been employed to display the scenarios. Such techniques are useful for assessing if the set of scenarios considered is comprehensive. It is recommended that further consideration is given to the selection of scenarios based on site-specific data.

Fundamental to the assessment of a given scenario is the definition of appropriate critical groups. Critical groups, in a broad sense, are the members of the local population who are likely to suffer the highest radiation exposures, under the conditions of the scenario. Three broad classes of critical group were considered, namely subsistence communities who will tend to settle and stay put for a reasonable period of time (henceforth referred to as ‘settlers’), Aboriginal or other groups who may settle in the region of the repository, but then move on after a period of weeks as part of their nomadic hunter–gatherer lifestyle (henceforth referred to as ‘nomads’), and outside workers who enter the repository zone to undertake a specific work task, and then leave once the work has been undertaken.

Outside worker critical groups are defined only for specific, short-term human intrusion scenarios. For the other scenarios, where exposures can occur over a much longer period, both settler critical groups and nomadic groups are defined.

For the scenarios that involve longer-term exposures, the settlers are considered to constitute the critical groups that will receive the highest radiation doses (nomads can be expected to receive substantially lower doses, on account of their more transient presence in the vicinity of the wastes), but both critical groups are assessed in detail in this report. To summarise, the following critical groups have been considered:

- Settler groups constitute communities who may settle in the region of the repository, and remain there for a number of years.
- Nomadic groups constitute communities who may settle in the region of the repository, but who may then move elsewhere within a period of weeks.
- Outside workers are defined only for short-term human intrusion scenarios.

As none of the scenarios outlined above are *certain* to occur, it is appropriate to consider the radiological performance of the repository in terms of estimated risks of cancer induction and serious hereditary effects. As used in this context, the term ‘risk’ implies a probability, and as such is equal to the probability of occurrence of the scenario multiplied by the probability of cancer induction or serious hereditary effects, given that the scenario occurs.

In Section E8.2, a brief description of the proposed disposal structure is provided. This is of course subject to change, and reflects current views on issues such as repository depth, cap thickness, repository volume. In Section E8.3, a description of the regulatory context is given, along with a discussion of the approach adopted for the assessment of doses and risks arising from the wastes in the proposed repository. In Section E8.4, the scenarios considered in this assessment are described and appropriate critical groups are defined. In the context of the proposed Australian repository, there are three distinct critical groups, as described above. Section E8.5 provides a description of the equations used to assess radiological doses and risks, along with parameter values for use with the dose equations, for the appropriate critical groups. Section E8.6 discusses the results obtained for the human intrusion and natural disruptive events scenarios.

In Section E8.7, the radiological impact of human contact with spent sources is considered. Contact with spent sources can only arise if some form of excavation is undertaken at the repository site, and the sources are moved from being buried to areas accessible by humans. Although the radiological consequences of, for example, holding a source in the hand or pocket will be considerable, it should be borne in mind that the probability of this actually occurring is low.

In Section E8.8, the assessment of doses arising from gas emanation from the repository is discussed. Radioactive gases that need to be considered include hydrogen-3 (as tritiated hydrogen and tritiated water), carbon-14 (as $^{14}CO_2$ or $^{14}CH_4$), krypton-85 and radon-222 (which arises from the radioactive decay of radium-226). In this case, the critical group of interest could be either settlers or nomads, the only difference between the two cases being the period of occupancy of the house or dwelling.

In Section E8.9, the problem of radionuclides leaching from the repository, in groundwater, through to the underlying aquifer is considered. Because the repository is located in the unsaturated zone, the computation of concentrations at points in the aquifer and in the unsaturated zone below the repository is complicated. The moisture content of the underlying rock is determined from Richard's equation, and the radionuclide concentrations can be obtained by solving the advection–dispersion equation for unsaturated regions. Instead of carrying out this complex analysis, simpler decay and dilution arguments are used to show that concentrations in the underlying aquifer are likely to be several orders of magnitude smaller than would be expected in porewater, on the basis of natural radionuclide activity levels.

Finally, Section E8.10 summarises the results obtained in the present assessment, and considers the assumptions made to carry out the assessment. Future work to improve the credibility of the assessment is also discussed.

It should be noted that the assessment in this report is based on the best estimate of the total radionuclide inventory (current plus estimated future arisings for the next 50 years). The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) would determine the total radionuclide inventory (both for bulk material and for individual sources) acceptable for disposal at the repository. ARPANSA would take into account the exact location of the site, the detailed repository design and the acceptance and verification of the scenarios and assumptions used in the risk assessments.'

E8.2 Inventory and Design

E8.2.1 Site Selection

The objective of radioactive waste disposal is to provide sufficient isolation of the waste from the biosphere to ensure adequate protection for human health and the environment over the period of the hazardous life of the waste. The isolation potential of the chosen disposal method should be commensurate with the hazard potential and the longevity of the waste. Two approaches are usually considered, depending on the nature of the wastes to be disposed. These are near-surface disposal and deep disposal. According to the International Atomic Energy Agency (IAEA), near-surface disposal is permitted, provided that the wastes satisfy certain criteria in terms of the specific activity of the wastes (International Atomic Energy Agency 1995).

All three sites selected for further evaluation have been found to be highly suitable and a preferred site has been identified which better meets more of the selection criteria. All three sites have the following desirable characteristics:

- low population densities
- very low rainfall and high evaporation rates
- good surface drainage
- low groundwater tables
- sufficient clay and other adsorbing materials to retard radionuclide migration in the unlikely event of leaching from the repository.

A low population density is desirable because it limits the number of people who would potentially be exposed to radioactive materials located in the repository. Low rainfall, high evaporation rates and good surface drainage act to ensure that the groundwater table stays well below the levels to which a near-surface repository would penetrate. This minimises the possibility of radioactive wastes leaching from the repository and finding their way into local groundwater systems, from where they could migrate to locations distant from the repository site.

E8.2.2 Radionuclide Inventory

The radionuclide inventory and future waste suitable for disposal at the national repository are discussed in Chapter 4 of this draft environmental impact statement.

In the simplified approach adopted in the calculations reported here for the intrusion and climate change scenarios, it is assumed that the inventory is uniformly distributed throughout the repository. Any local concentrations of radioactive materials could, of course, lead to higher doses than those that are estimated in this report. This is investigated in Section E8.7.

The estimated inventory of radionuclides, at the time of repository closure (based on available information at the time of writing), is shown in Table E8.1. This estimated inventory is based on a projected final trench volume of 10,000 m^3, with total radionuclide activity estimates projected from the existing inventory of known category A, B and C wastes, and anticipated future arisings. A breakdown of the contributions from key radionuclides in the current waste inventory is shown in Table E8.2.

TABLE E8.1 Proposed inventory of radionuclides for the national repository[(1)]

Radionuclide	Activity level for near-surface disposal (Bq)	Radionuclide	Activity level for near-surface disposal (Bq)
Ac-227	6.53E+08	Ir-192	4.46E+09
Ag-108m	0.00E+00	Kr-85	6.99E+09
Am-241	2.34E+11	Na-22	0.00E+00
Am-241/Be	8.94E+09	Ni-63	4.11E+09
Ba-133	3.79E+08	Np-237	2.18E+08
Be-10	0.00E+00	Pa-231	0.00E+00
Bi-207	2.72E+05	Pb-210	2.87E+07
Bi-214	0.00E+00	Pm-147	2.45E+11
C-14	9.69E+05	Po-210	2.87E+07
Cd-109	4.03E+08	Pu-238	0.00E+00
Cf-252	2.04E+08	Pu-239	0.00E+00
Cl-36	0.00E+00	Ra-226	8.13E+10
Cm-244	0.00E+00	Ra-226/Be	1.20E+09
Co-57	0.00E+00	Ru-106	8.71E+08
Co-60	1.15E+12	S-35	0.00E+00
Cs-134	2.49E+08	Sb-124	0.00E+00
Cs-137	1.82E+12	Sb-125	1.72E+09
Eu-152	5.65E+09	Sn-113	0.00E+00
Eu-154	7.60E+08	Sr-90	9.38E+10
Fe-55	1.63E+06	Th-230	2.87E+07
Gd-153	0.00E+00	Th-232	7.51E+09
H-3	1.55E+12	Tl-204	1.63E+09
Ho-166	4.03E+08	U-234	2.87E+07
I-125	0.00E+00	U-235	3.57E+09
I-129	1.61E+06	U-238	1.20E+11

(1) Estimated total radionuclide inventory (current plus estimated future arisings for the next 50 years)

TABLE E8.2 Origins of the key radionuclides

Description	^{3}H	^{60}Co	^{90}Sr	^{137}Cs	^{226}Ra	^{232}Th	^{238}U	^{241}Am
ANSTO	1.70E+10	3.33E+11	1.44E+10	2.84E+11	2.80E+09	3.05E+09	1.40E+10	2.40E+09
CSIRO (soil)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+07	2.00E+08	1.32E+07	0.00E+00
CSIRO (other)	1.65E+05	1.86E+11	3.58E+09	5.02E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other Commonwealth	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
States / territories	1.30E+11	1.78E+09	1.70E+10	3.59E+10	2.16E+10	8.39E+05	6.53E+06	1.05E+11
Defence (St Mary's)	0.00E+00	8.23E+09	8.05E+09	1.25E+10	6.70E+09	0.00E+00	0.00E+00	0.00E+00
Defence (other)	5.64E+11	1.12E+09	0.00E+00	0.00E+00	6.25E+09	2.01E+08	4.13E+10	0.00E+00

E8.2.3 Proposed Design of the Repository

In considering the optimum design for the Australian National Repository, a number of questions need to be considered. These include:

- the requirement for a base slab to facilitate potential liquid effluent monitoring
- the requirement for compartmentalisation of the trench
- waste segregation issues
- cap design, including possible compartmentalisation
- locations for monitoring gas emissions.

It can be seen that the repository could, in principle, be a relatively complex structure, with a number of trenches and compartments and a cap designed to provide optimum protection to the general public. Some waste could also be disposed of in boreholes. However, for the purposes of the current preliminary assessment, a simpler conceptual design was considered (see Figure E8.2).

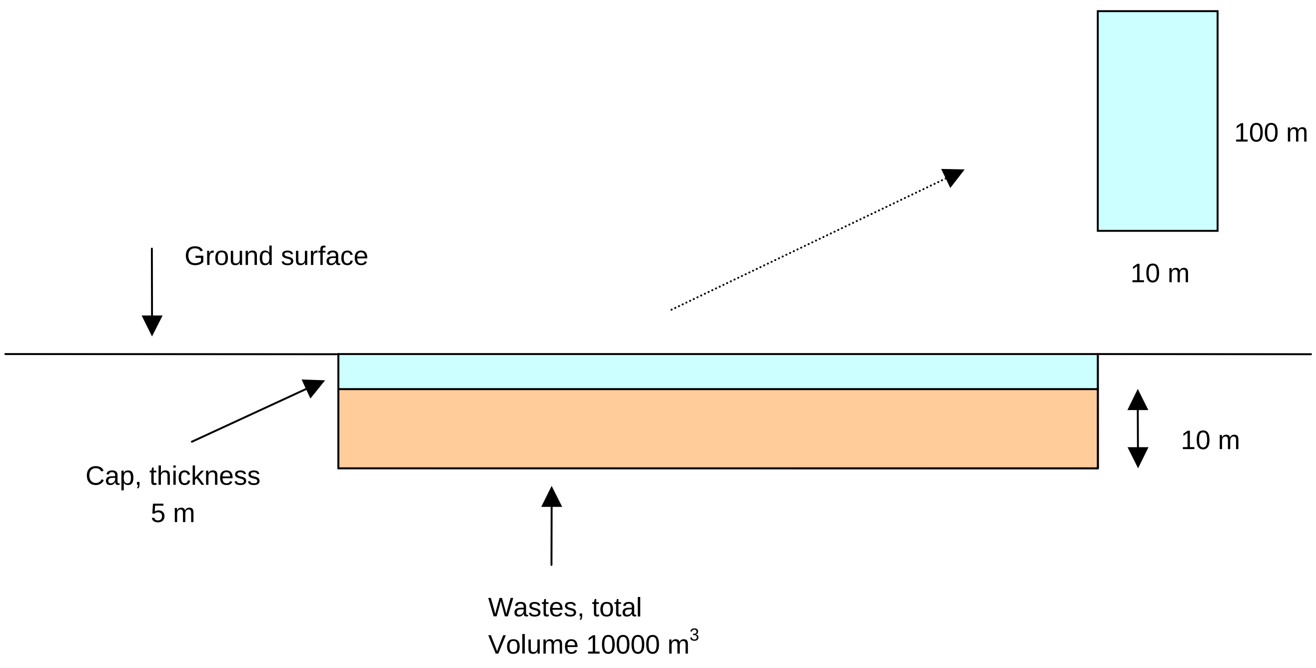

FIGURE E8.2
Simplified repository design for preliminary assessment

It is assumed that the total volume of waste packages is around 10,000 m^3, and that these will be buried in a trench with a cap of thickness 5 m over the top. It is assumed that the dimensions of the trench will be 100 × 10 m on the ground surface, and so the wastes will occupy a depth of about 10 m. If the cap has thickness 5 m, this means that the wastes will lie between 5 m and 15 m below the ground surface. Figure E8.2 should be considered as illustrative only.

In order to undertake the preliminary assessment, it was assumed that the wastes are distributed homogeneously throughout the volume of the repository (excluding the cap). In practice, the wastes will be heterogeneously distributed; in particular, spent sources (e.g. medical radiation sources) will be compact packages of high activity. Contact with a spent source could lead to deterministic radiation effects (e.g. skin erythema or even the haemopoietic syndrome), which would not occur even after prolonged exposure to more inert wastes. This issue is investigated in more detail in Section E8.7.

However, the assumption that the wastes are homogeneously distributed has an important consequence. In many scenarios, the wastes of the repository are exposed to the local population, and exposures will occur as they move around at the repository location. With the assumption of homogeneous distribution, no account needs to be taken of the precise position in the repository at which such interactions occur. However, the disadvantage of this approach is that no information can be obtained on the variability of doses through intrusions into different sections of the repository (that is ‘hotspots’ are not taken explicitly into account).

E8.3 Approach to the Assessment

In undertaking a radiological performance assessment, a number of issues need to be considered. One of the most important considerations is the regulatory context under which the results of the assessment will be examined. The regulatory context will define, among other things, the dose or risk targets and limits against which the results of the assessment must be compared. Secondly, scenarios that involve consideration of future human behaviours are subject to guidance about how to define that human behaviour.

For each scenario, one or more critical groups need to be defined. Critical groups are groups of hypothetical individuals who will be expected to receive the greatest doses and risks under the conditions of the scenario. For the proposed national repository, three sets of critical groups are defined, based on settler and nomadic behaviour, and outside workers for the short-term human intrusion scenarios. Each critical group will be exposed through a number of exposure pathways. For scenarios that are not certain to occur, a risk-based approach is the preferred approach, and this in turn involves consideration of the probability of occurrence of the scenario

E8.3.1 Introduction

The approach adopted for the present preliminary assessment is shown diagrammatically in Figure E8.3. The various stages of the assessment are described below.

Once a disposal concept has been identified, it is first necessary to develop the context under which the disposal concept is to be assessed. The BIOMASS (1999) study identifies a number of different aspects that define the assessment context:

- assessment purpose
- assessment endpoint
- repository type
- assessment philosophy
- site context
- geosphere–biosphere interface
- source term
- societal assumptions
- time frame.

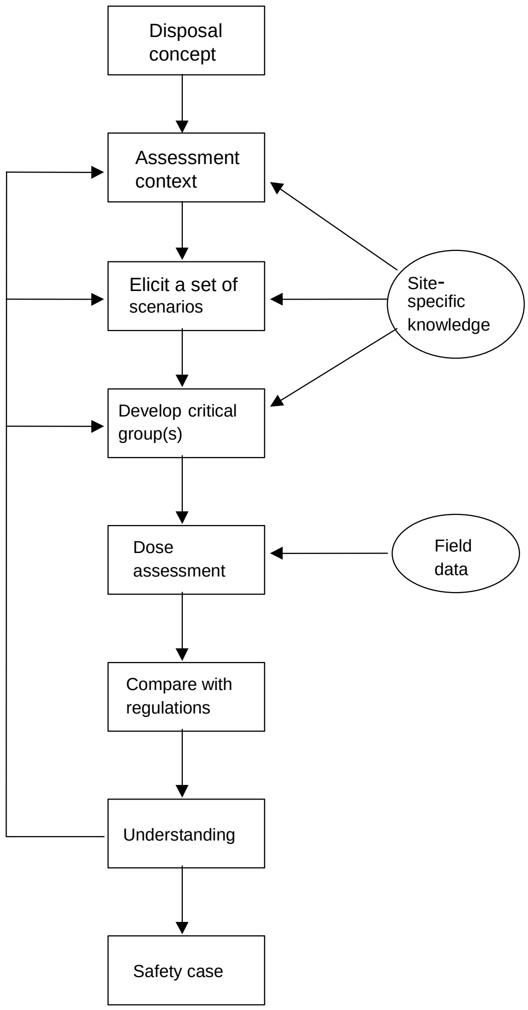

FIGURE E8.3
Approach to assessment

The purpose of the present assessment is to inform judgment about the suitability of the preferred site (Site 52a) in terms of radiological safety, albeit at a preliminary level. The assessment endpoints are individual dose and risk, and the repository type is a near-surface facility. The assessment philosophy adopted herein is to use a cautious approach, in which uncertain parameters are assigned values that would lead to the greatest radiological impact, but which nevertheless retain an element of plausibility. Modelling assumptions follow the same philosophy of caution.

The site context is a near-surface repository located in the central–north of South Australia. The desirable features of this location are specified in Section E8.2.1. This region of Australia is arid at the present time, with the watertable located many tens of metres below the ground surface. This situation is not expected to change in the next 10,000 years. Therefore, transport of radionuclides in the geosphere, and consequent return to the biosphere in groundwater, are not considered explicitly in this assessment. However, extraction of waters are considered, from within the repository zone itself (see Section E8.4) and from the underlying aquifer (Section E8.9). The source term is defined by the radionuclide inventory and proposed repository parameters given in Tables E8.1 and E8.3, respectively.

At present, the preferred repository site is located within the Woomera test range, and hence would not be accessible to Aboriginal or other critical groups. However, it will be assumed that the protection afforded by the test range fencing and other deterrents will cease to be active at some stage in the future, so that the repository site is fully accessible.

TABLE E8.3 Parameter values for the proposed national repository

Quantity	Units	Value
Repository volume	m^3	10,700
Density of wastes	kg/m^3	1,500
Porosity of wastes	–	0.3
Depth of wastes	m	5
Repository cross section	m^2	10,000
Cap thickness	m	5
Spoil density	kg/m^3	1,500
Spoil porosity	–	0.3

Source: RWE Nukem

Three distinct types of critical group will be considered, namely nomadic Aboriginal communities (who are not now present in the region, but could conceivably more back into the region in the future), settler communities who live a 'European' lifestyle, and who settle permanently in the vicinity of the wastes, and outside workers. In the absence of regulatory guidance to the contrary, the time frame of the assessment will be taken as 10,000 years, though results will be presented for times beyond this, to illustrate how the facility performs far into the future.

Once the assessment context is defined, the next stage is to define a set of scenarios, and the critical group(s) that are to be associated with the scenarios. This is discussed in Section E8.4 for the human intrusion and natural disruptive event scenarios. Note that scenario and critical group definition, along with the assessment context, cannot be undertaken solely by experts remote from the region where disposal is being considered. Input from experts with knowledge of the site itself is required, to ensure that a comprehensive analysis is provided.

The scenarios and critical groups are then subject to dose assessment. The approach adopted is described in Section E8.5, and the results are described in Section E8.6. A key input to the dose assessment is field data, in the form of critical group characteristics (e.g. consumption rates and occupancy times) and radionuclide-specific parameters, for example transfer factors from soils to plants and animals.

The results of the dose assessment can be compared with regulatory targets, if required. In this study, risk calculation results are compared with an individual risk target of 1×10^{-6}/yr, and for the human intrusion scenarios, individual doses are also compared with the intervention levels of 10 mSv/yr and 100 mSv/yr, as advocated by International Commission on Radiological Protection (ICRP) publication 81 (1998). ICRP 81 provides the latest recommendations on assessment approaches for the disposal of solid radioactive waste, especially with regard to human intrusion (see Section 3.3.2). It might be worth considering whether such advice should be applied in the context of assessments of the proposed Australian repository. In this report, both a risk target and the dose intervention levels advocated by ICRP 81 are used.

Consideration of the assessment results and the relationship to regulatory targets enables further understanding of disposal performance to be obtained. For example, if doses and risks are substantially below the appropriate targets, then it may not be necessary to assess further and a safety case can be developed on the basis of those results. Conversely, if doses and risks are close to the corresponding targets, then it may be necessary to consider the need to optimise or reconsider the design of the repository, or to consider the need to gain further information about the disposal site (e.g. to carry out a more realistic analysis). It may be necessary to consider additional scenarios and critical groups.

In practice, most performance assessments proceed in this way, with a number of 'iterations' of the assessment taking place before a safety case can be developed.

E8.3.2 Regulatory Context

During the operation of a near-surface repository, the exposures of the repository workers and others can reasonably be predicted, as the times of exposure are known, and other controlling factors such as beta and gamma dose rates can be measured. In such situations, where an exposure is actually occurring or is certain to occur, the ICRP recommends the use of a dose assessment and associated dose limits as a basis for assessment of the safety of the facility (International Commission on Radiological Protection 1991). For members of the public, the dose limit is an annual effective dose of 1 mSv above the ambient background dose rate. For occupationally exposed workers, the dose limit is 20 mSv/yr, averaged over a five year period.

After the near-surface repository is closed and the period of institutional control has ended, it becomes more difficult to predict the exposures that will occur. These exposures are not certain to occur, and are likely to be the result of specific actions on the part of those who are exposed. In such cases, the ICRP (1991) recommends the use of a risk-based assessment and risk limits for assessment of the safety of the facility. However, in the specific case of human intrusion scenarios, later advice from the ICRP seems to favour the use of dose-based intervention levels.

Radiological risk is defined as follows:

$$R = rPH \tag{3.1}$$

Where R (yr^{-1}) is the individual risk
H (Sv) is the effective dose conditional on intrusion taking place
r (Sv^{-1}) is the dose-to-risk conversion factor
P (yr^{-1}) is the probability of exposure in any one year.

It should be noted that this expression, strictly speaking, is only valid for low levels of radiation exposure, where stochastic effects of radiation predominate, as opposed to deterministic effects (i.e. effective doses less than about 0.5 Sv). Risk is normally expressed as an annual probability; the factor *rH* is the probability of inducing a fatal cancer or serious hereditary effect, given that the exposure occurs.

The current position concerning the regulation of near-surface disposals in Australia is set out in the National Health and Medical Research Council codes of 1992 and 1997. The following criterion is relevant:

> The exposure of individuals resulting from a combination of all the relevant practices should be subject to dose limits or to some control of risk in the case of potential exposures (individual dose and risk limits). (NHMRC 1992 Code)

The NHMRC 1997 Code suggests that an effective dose limit of 1 mSv/yr and a risk limit of 5×10^{-5}/yr (for a site in an arid region for which no other potential artificial sources of exposure exist for members of the critical group) should apply, although effective doses higher than 5 mSv/yr may be acceptable if they are restricted to one year. No time cut-off is specified beyond which the radiological consequences of disposal need not be considered.

However, following advice from ARPANSA, in this assessment radiological doses and risks from human intrusion were estimated and compared with an effective dose limit of 1 mSv/yr and a risk limit of 1×10^{-6}/yr. For the assessment of the consequences of climate change, only radiological doses were estimated and compared for particular scenarios, because no information was available on the likelihood of different climate scenarios. Calculations were performed for timescales up to 10,000 years, in the absence of specific regulatory guidance regarding assessment timescales.

E8.3.3 Treatment of Human Intrusion

As illustrated in Figure E8.1, there are four principal routes by which radionuclides can be returned to the accessible environment. The groundwater pathway, gas pathway and natural disruptive event pathway can be treated by considering how the disposal system will evolve under scenarios pertaining to these pathways. Human intrusions are somewhat different, in that the behaviour of humans is intrinsically more difficult to predict, particularly in the far future where technological advances may mean that human behaviour is different from that observed today

Because of this and the fact that human intrusions can lead to substantial radiological consequences, the human intrusion pathway is a very important one, and as such has been subject to considerable discussion in recent years. Two recent documents provide alternative international views on how the human intrusion pathway should be addressed in performance assessments of radioactive waste repositories:

1. Discussions on the treatment of the human intrusion pathway were held under the auspices of the Nuclear Energy Agency (NEA). The NEA Working Group Report (1995) makes a number of recommendations for the treatment of future human actions (or human intrusion) in performance assessments.
2. In 1998, the ICRP (Publication 81) issued recommendations on radiological protection applied to the disposal of long-lived solid radioactive waste. The recommendations covered the treatment of human intrusion.

In the next subsection, the main recommendations of the NEA Working Group Report (1995) are summarised and discussed in relation to the assessment reported here.

NEA Advice on Human Intrusion

The NEA makes the following broad level recommendations, with regard to the treatment of human intrusions in radiological performance assessments.

Deliberate human intrusion need not be considered.

Deliberate human intrusion refers to those intrusions undertaken by persons with a knowledge of the wastes that are stored in the region into which they are intruding. Such persons are considered to be responsible for their own actions, and are usually not considered in safety assessments.

The same quantitative basis should be used to assess the impact of the human intrusion pathway as for other pathways.

Calculations should be considered illustrative rather than predictive.

A full assessment of the post-closure safety of the national repository has to extend over periods of thousands of years because of the long half-lives of some of the wastes stored there. Over this period of time, the form of human society will change in a manner that is impossible to predict. Calculations of dose or risk cannot be considered to be predictive and must be viewed as illustrative.

A range of scenarios should be considered.

The range of scenarios addressed in the assessment is discussed below in Section E8.4.

Calculations should be based on current practice at the site or at an analogue site.

Because future human behaviours cannot be predicted, the recommended approach is to base calculations on current technology and on current patterns of behaviour in the locality of the site or, in the absence of suitable information, at analogue locations. The modes of intrusion considered should be those that might occur given present economic needs and technology and the current pattern of resource exploitation.

For example, it might be assumed that drilling would be undertaken in the area using the type of technology used today for site investigations or geological surveys, but not that new technology will be developed in the future that would remove the need for drilling to obtain data. This basic approach of assuming scenarios based on current technology and behaviour has been widely used in performance assessments in many national programmes (e.g. see Wuschke 1991; Hirsekorn 1989; Anderson et al. 1989) and was adopted here.

It was agreed by the NEA Working Group that a number of countermeasures (measures that would reduce the likelihood of human intrusion) should be *considered* (it was not recommended that all would be required):

- Disposal facilities should be located away from areas of currently recognised subsurface resource potential.
- Waste should be isolated from the human environment.
- Optimisation of the design of facilities should be considered to minimise the risk from human intrusion.
- Information on the location of the facilities should be conserved.
- Durable markers should be placed at or near the site.
- Physical barriers that could prevent human intrusion (e.g. thick concrete) should be provided.

ICRP 81 Recommendations for Human Intrusion

The following important recommendations are made in ICRP Publication 81 (1998) on how to assess human intrusion:

- In contrast to the views expressed by the NEA Working Group, it is recommended that, since there is no scientific basis for predicting the nature or probability of future human actions, it is not appropriate to include probabilities of such actions in a quantitative assessment that is to be compared with dose or risk constraints.
- For human intrusion, the consequences from one or more plausible stylised scenarios should be considered in order to evaluate the resilience of the facility to such events.
- Where human intrusion could lead to doses to those living around the site that would be sufficiently high that intervention on current criteria would almost always be justified, reasonable efforts should be made at the facility development stage to reduce the likelihood of human intrusion or to limit its consequences.
- For doses below 10 mSv/yr, intervention is not always likely to be justifiable, but above 100 mSv/yr intervention should be considered almost always justifiable.

A view needs to be reached on the appropriate approach to adopt in assessing human intrusion for this proposed facility. In the current report, estimates of dose and risk are provided, and interpretation in terms of both a risk-based target and the ICRP 81 approach are given, pending agreement as to the appropriate approach.

The approach taken to selecting scenarios, performing calculations of consequences, and assessing the significance of the results of the calculations is discussed in the next section.

E8.3.4 Dose Assessment for Human Intrusions and Natural Disruptive Events

The assessment approach adopted in this report for human intrusions and natural disruptive events can be summarised in the following steps:

1. Select a number of exposure scenarios.
2. Define the critical group(s) appropriate to each scenario.
3. Define the exposure pathways for each critical group.
4. Define the behaviour of the critical group in terms of exposure times, intake rates, etc.
5. Evaluate doses and risks to the critical groups, and compare them with appropriate target dose and risk values.

The most satisfactory means of selecting a set of scenarios is to use formal methods (see Kelly and Billington 1997). These involve assessment and local experts sitting together and developing ideas based on their knowledge of the proposed disposal site and the way in which the repository and its environs are likely to evolve in time. Such approaches have the benefit of providing a traceable and auditable analysis that can be scrutinised and revised as new knowledge and information becomes available.

However, formal approaches are often costly to implement, and it is often more convenient, particularly in a preliminary assessment of the type reported here, to refer to tabulated lists of scenarios. For human intrusion scenarios, the list provided by the NEA (1995) is a good starting point. For other scenarios, the list compiled by the ISAM programme of IAEA (2000) is appropriate. Both sources were used as background to the selection of the scenarios described in Section E8.4.

Once the exposure scenarios have been defined, it is necessary to determine the critical groups who will suffer the greatest exposure under these scenarios. In many cases the choice will be obvious, as the scenario itself will be defined in terms of some type of human behaviour. For example, a borehole drilling scenario will have, as its critical group, the workers who undertake such drilling and analyses. In other cases the choice may be less obvious. In the scenario that describes a wetter climate, for example, it is usual to postulate that the most exposed group will be a subsistence community that sets up a farm or similar residence in the vicinity of the repository site, and that uses the land overlying the repository for grazing animals or planting crops.

From the three broad classes of critical group (see Section E8.1) the settler groups are likely to spend more time in contact with repository materials, and are therefore the ones considered to be at greatest risk. However, dose and risk calculations have been undertaken for both settler and nomadic groups, in scenarios involving longer-term exposures.

There are a number of ways in which critical groups can receive a radiation dose from materials disposed of in the repository, as a result of human intrusions or natural disruptive events. These include:

- external irradiation (from gamma emitting radionuclides)
- inhalation of contaminated dust
- ingestion of contaminated soils and dust
- intake of radionuclides through cuts and wounds
- ingestion of contaminated plant material
- ingestion of contaminated animal foodstuffs
- ingestion of contaminated waters.

Of course, not all of these pathways will apply to all critical groups, and so it is necessary to decide which exposure pathways apply to each critical group. For example, it is unlikely that borehole drillers will consume contaminated animal produce at the repository site.

Once the critical groups have been identified, it is necessary to define their behaviour in terms of parameter values that can be used in dose equations. The two most important quantities are exposure times and intake rates. Thus, to calculate external gamma doses, it is necessary to know the amount of time a critical group member spends in the vicinity of contaminated material. For a borehole driller, it may be postulated that the driller spends 30 minutes examining one core. Intake rates are required to calculate internal doses. Thus, it is necessary to know the annual consumption of plant or animal foodstuffs, in order to calculate doses arising from consumption of these materials.

Many of the quantities will be uncertain. For example, it is only possible to make plausible estimates of the amount of time that a farmer spends out in the field, or for how long a borehole driller is in contact with a contaminated borehole core. In addition, the exact amount of foodstuffs consumed by a critical group member is impossible to predict. However, it is possible to gain some insight into these values by considering present day working practices, or by examining or undertaking habit surveys. Food habit surveys have been used in this assessment, where available. The resulting parameter values for exposure times and consumption rates can be considered to be *representative*, in the sense that any individual is unlikely to exhibit behaviour that differs by more than a factor of two in respect of these parameter values.

Radiological doses and risks are obtained by using the equations set out in Section E8.5. All doses are expressed as effective doses. The general approach adopted for dose assessment is broadly similar to that advocated by the international BIOMASS working group (1998).

E8.3.5 Dose Assessment for the Gas Pathway

There are a number of mechanisms occurring during the natural evolution of a waste repository that can give rise to gas generation and migration upwards and out of the top of the repository. For example, the corrosion of steel waste canisters can give rise to hydrogen gas, microbial degradation of cellulose can give rise to carbon dioxide and methane, and radiolysis can also give rise to gas production and release. The generation of gaseous products and their release from the repository are discussed further in Section E8.8.

There are two principal ways in which gaseous products from the repository can have a radiological impact on the human population. ^{3}H and ^{14}C labelled gases can be incorporated into soils and taken up by plants and animals, which are subsequently used as food produce. In addition, there are the direct effects of gas that emerges out of the repository. In many circumstances, the gases will emerge into the outside environment, and will be rapidly dispersed throughout the atmosphere to negligible levels. However, if a house, dwelling or other type of building were located on top of the repository, the gases could enter the building, and build up to appreciable levels, alleviated only by removal through ventilation and radioactive decay. ^{222}Rn, which is produced from the decay of ^{226}Ra, is a universal hazard as a consequence of build-up in occupied buildings.

The critical group is taken to be a family of settlers who build their house on top of the waste repository, and who occupy the house for 16 hours per day. The approach adopted in this assessment can be summarised in the following steps.

1. Estimate the emanation rate of gases out of the repository.
2. Calculate the concentration of gas in the building structure.
3. Estimate the radiological impact, based on breathing rates and occupancy.

The detailed procedure and results are described in Section E8.8.

E8.3.6 Treatment of Groundwater Leaching

In many assessment contexts, the leaching of contaminants from the repository in groundwater is the main transport pathway of interest. However, present day conditions at Woomera indicate an arid environment, with the watertable some 40–70 m below ground surface. In such circumstances, issues such as repository resaturation and consequent dissolution and leaching of radioactive materials is of lesser importance. Nevertheless, while future climate studies (see Appendix F) indicate that there is unlikely to be a transition from an arid to a temperate climate state in the next 10,000 years or so, there is the possibility of localised and short-term storm events that could lead to infiltration through the repository, with radionuclides being leached downwards through the unsaturated zone, in the direction of the underlying aquifer. It is therefore of interest to investigate the possibility that radionuclides could reach the aquifer in sufficient quantity to contaminate the groundwater carried therein.

The calculation of groundwater flow and radionuclide transport in unsaturated conditions is somewhat more complex than for fully saturated conditions. Groundwater flow is obtained by solving the non-linear Richard's equation, and radionuclide transport is obtained by solving an advection–dispersion equation for which the transport parameters (e.g. advective flow velocity and dispersion coefficients) are functions of the ground moisture content. This approach was not adopted in this assessment. Instead, the following procedure was followed.

1. Obtain the groundwater travel time from the base of the repository to the aquifer.
2. Obtain retarded travel times, based on adsorption characteristics of individual radionuclides.
3. Compare retarded travel times with radioactive half lives and assessment timescales.
4. Estimate dilution factors for those radionuclides able to reach the aquifer.

The full procedure is described in Section E8.9 of this report.

E8.4 Scenarios and Critical Groups

In this section, the choice of scenarios to be taken forward for dose and risk assessment is described. Scenarios for human exposure from repository wastes can be formulated in a number of ways, ranging from consideration of experience from previous repository assessments, through to formal, *ab initio* approaches that are tailored specifically to the specific problem under consideration. In many regards, formal methods are the most satisfactory means of eliciting exposure scenarios, especially in situations where there is a regulatory requirement to demonstrate thoroughness of analysis. However, in practice, they are costly to implement and frequently add little additional information to what is obtained by considering previous assessment experience. The most effective approach is to consider an intermediate scheme, in which previous experience is augmented by site-specific scenarios and internationally recognised lists of features, events ands processes.

After due consideration of the NEA list of human intrusion scenarios (1995), the ISAM list of scenarios appropriate to a near-surface repository (ISAM Programme of IAEA 2000), conditions likely to prevail at the Woomera site and experience with previous near-surface assessments, it was decided that the following exposure scenarios should be considered in this preliminary assessment of the proposed national repository:

1. the effects of drilling and examination of borehole cores
2. the effects of bulk excavation of contaminated materials
3. the effects of building a road that runs across the repository
4. the effects of archaeological digging at the site
5. the longer-term effects arising from exposure to materials excavated in scenarios 2 and 3
6. the effects of a rocket crash from the nearby Woomera test site
7. the effects of an aircraft crash onto the repository site
8. the effects of a transition to a wetter climate state
9. the effects of gross erosion
10. the effects of site flooding in the wetter climate state
11. the effects of consuming contaminated waters obtained from a well drilled through the wastes
12. the effects of radioactive gas build up in a house on the repository.

It is not claimed that this list of scenarios is a comprehensive or exhaustive list of possible future happenings at the site. However, for the purposes of a preliminary assessment, these scenarios will broadly scope the range of consequences that might be expected to arise. A diagrammatic representation of these scenarios is shown in Figure E8.4. The level structure shows the relationship between individual scenarios, and how they fit into the overall framework of phenomena that could potentially affect the performance of the proposed repository. The tree structure also facilitates elicitation of additional scenarios that have not been considered in the present analysis.

Other scenarios were considered (in the context of a preliminary assessment) as unlikely to occur, or it was decided that the expected consequences were similar to one of the scenarios considered above. For example, it was decided that activities such as mineral exploration or scientific exploration would involve procedures similar to borehole core drilling. A fuller discussion of possible human intrusion scenarios was provided in a similar assessment, undertaken by AEA Technology, of the disposal of plutonium at the Maralinga test site (Baker et al. 2001).

It may be argued that releases to groundwater and transport in the saturated zone would occur in a wetter climate, but it is judged that the radiological doses and risks that would result would be lower than would occur as a result of human intrusion and other activities involving direct interaction with the repository and its wastes. Radiological consequences would arise as the result of contamination of soils or surface wasters in the area where contaminated water discharges to the ground surface. Such concentrations would be lower than those in the wastes, owing to dilution and dispersion in uncontaminated waters. Radiological consequences are likely to be lower than those calculated for soils with activity concentrations identical to the waste for agricultural purposes. The effects of leaching of radionuclides downwards, through the unsaturated zone, are considered in Section E8.9.

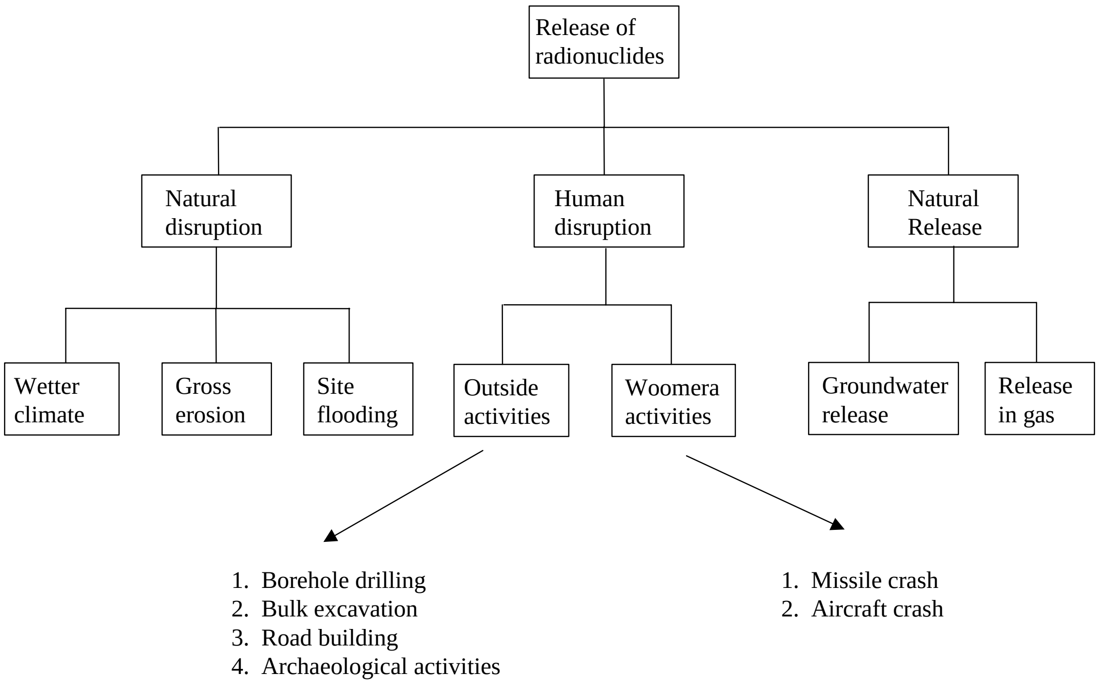

FIGURE E8.4
Structure of scenario definitions

Each of the scenarios described above requires the definition of a critical group. As has been stated earlier, both settler and nomadic critical groups are taken into account. In the following subsections, the appropriate settler critical groups are defined, as it is these critical groups that would be expected to receive the highest doses. Table E8.4 lists the critical group for each scenario and Table E8.5 displays the exposure pathways arising from each scenario. Some remarks are provided about the corresponding nomadic critical group, where these would differ substantially from that defined for the settler groups. For the first three scenarios, the critical groups would correspond neither to the settler or nomadic groups, as they would be workers who come from outside the area, and then leave the area again once their work is complete.

TABLE E8.4 Summary of scenarios and critical groups

Scenario	Critical Group
Borehole drillers	Geotechnical workers
Bulk excavation	Excavation workers
Road builders	Road building gang
Archaeologists	Group of archaeologists
Longer term exposures	Group who use excavated materials in gardens (settlers) or who camp in the vicinity of materials (nomads)
Rocket crash	Children playing at site. The critical group is the same for both settlers and nomads
Aircraft crash	Aircraft recovery team
Wetter climate	Subsistence/farming community (settlers) or a group that hunts wild animals and picks wild plants (nomads)
Gross erosion	Subsistence/farming community (settlers) or a group that hunts wild animals and picks wild plants (nomads)
Site flooding (bathtubbing)	Subsistence/farming community (settlers) or a group that hunts wild animals and picks wild plants (nomads)
Contaminated well waters	Subsistence/farming community (settlers) or a group that uses traditional techniques to extract water (nomads)
Gas emanation	Settler family occupying house on top of repository

TABLE E8.5 Exposure pathways considered for the human intrusion and natural disruptive event scenarios

Scenario	External	Ingestion of dust	Inhalation of dust	Ingestion of plants	Ingestion of animal	Ingestion of water
Borehole drillers	Y	Y	Y			
Bulk excavation	Y	Y	Y			
Road builders	Y	Y	Y			
Archaeologists	Y	Y	Y			
Longer term exposures	Y	Y	Y			
Rocket crash	Y	Y	Y			
Aircraft crash	Y	Y	Y			
Wetter climate	Y	Y	Y	Y	Y	Y
Gross erosion	Y	Y	Y	Y	Y	Y
Site flooding (bathtubbing)	Y	Y	Y	Y	Y	Y
Contaminated well waters						Y

In order to estimate radiological risks, it is necessary to estimate probabilities of occurrence for the scenarios. Usually these are expressed on the basis of an annual probability or frequency of occurrence. However, for scenarios such as climate change, such a quantity is not meaningful, and an overall probability of occurrence is required. Probabilities of this type are dimensionless. Frequencies and probabilities of occurrence are also set out in the following subsections.

E8.4.1 Borehole Drilling

Critical Groups

In this scenario, it is assumed that a single borehole core is extracted from the centre of the repository, which is then examined by a geotechnical worker for a time period of 30 minutes. It is considered unlikely that more than one core would be extracted from the repository location.

The critical group therefore consists of an outside worker who enters the repository location to extract and examine a borehole core, after which he leaves the repository location. The geotechnical worker would suffer radiation exposure from the following pathways:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides.

External irradiation could also occur from beta-emitting radionuclides, but this is unlikely to be as important, and is not considered in this preliminary assessment.

Probability of Borehole Drilling

The most satisfactory means of estimating borehole drilling frequencies is to consider historical data for the region under consideration (assuming that all boreholes drilled were recorded). In undertaking this preliminary assessment, such information was not available, and so a cautious estimate of 1 borehole drilled per square kilometre per hundred years was assumed. Since the cross-sectional area of the repository is 10,000 m^2 (10^{-2} km^2), this leads to a drilling frequency at the repository of:

$$f(\text{borehole}) = 10^{-2} \times 10^{-2} = 10^{-4} \text{ boreholes/yr}$$

E8.4.2 Bulk Excavation

Critical Groups

In this scenario, it is assumed that bulk excavation of the disposed wastes occurs. A typical activity that could give rise to such a scenario is the drilling of trial pits, to investigate the underlying rock and soil characteristics. Such investigations are commonplace before building or other developments take place on open land.

The critical group therefore consists of an outside worker who enters the repository location to undertake the excavation work, after which he leaves the repository location, and hence is not associated either with settlers or nomadic people. The excavation worker would suffer radiation exposure from the following pathways:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides.

Probability of Bulk Excavation

As in the case of borehole drilling, historical records would provide the best starting point for estimating frequencies of bulk excavation. In the absence of such records, a cautious assumption will be made regarding the frequency of occurrence. It is considered that bulk excavation is as likely to occur as borehole excavation, and so the same frequency of occurrence is adopted, namely:

$$f(\text{bulk excavation}) = 10^{-2} \times 10^{-2} = 10^{-4} \text{ excavations/yr}$$

E8.4.3 Road Building

Critical Groups

In this scenario, the critical group is the team of workers engaged in building a road that runs across the repository. The team is assumed to spend 50 hours (i.e. about 6 working days) working on top of the repository site. It might be argued that road builders are unlikely to penetrate the 5 m cap that lies on top of the repository. However, it should be noted that the cap will degrade over time, and may not be present at that thickness several thousand years from now.

The critical group therefore consists of outside workers who enter the repository location to construct a section of road, after which they leave the repository location, and hence are not associated either with settlers or nomadic people. The exposure pathways for the road builders are:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides.

Probability of Road Building

The frequency with which a road is constructed and intersects a given disposal structure can be estimated from:

$$f(\text{road}) = \frac{\Delta + w}{Dt} \qquad (4.1)$$

where Δ (m) is the diameter of the disposal structure
w (m) is the width of a road, which is taken to be 5m
D (m) is the spacing between roads and is taken to be 10^5 m
t (yr) is the time period over which roads in the region are taken to have been built and is assumed to be 50 years.

This is believed to be a pessimistic estimate of the frequency with which contaminated material would be disturbed, since it is unlikely that the road foundations would reach to a depth sufficient to intersect the wastes under the 5 m cap. In the distant future (i.e. in a few thousand years' from repository closure), when the cap is likely to have eroded to some extent, it may be possible that road foundations could intersect the wastes. It is important to note this when interpreting the results of the dose calculation; while disruptive road-building practices cannot be ruled out at earlier times, it is likely that several thousand years of erosion will be required before it can realistically be expected to occur (see Section E8.4.9).

E8.4.4 Archaeological Activity

Critical Groups

In this scenario, the critical group is a number of archaeologists who explore the repository site. They are assumed to spend 200 hours at the repository site. This could be considered an over-estimate, especially if the archaeologists find nothing of interest at the site. However, many thousand years from now, it cannot be assumed that the repository contents will be of no interest.

The critical group therefore consists of archaeologists who enter the repository location to explore the site, after which they leaves the repository location, and hence are classed as outside workers. The exposure pathways for the archaeologists are:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides.

Probability of Archaeological Activity

Assessing the likely frequency of archaeological digs is not straightforward. As for borehole drilling, it might be possible to derive such information from historical records, but this has not been done for this preliminary assessment. Instead, a conservative estimate of 1 dig per square kilometre per hundred years has been taken. This leads to:

$$f(\text{archaeology}) = 10^{-2} \times 10^{-2} = 10^{-4} \text{ digs/yr}$$

E8.4.5 Long-term Exposure Following Excavation

Critical Groups

In this scenario, the critical group consists of those individuals who make use of contaminated materials that were excavated in scenarios 2 or 3 above (see Section E8.4). Such individuals would be settlers who might remove the excavated materials and use them as topsoil in their gardens, or more compact materials as foundation materials or for ornamental purposes. As the precise usage of such materials may be unclear, it has been pessimistically assumed that the critical group members spend up to 8 hours per day in contact with the materials (corresponding, for example, to a field worker who uses the materials for topsoil).

In a quantitative assessment of doses to nomadic people, the analogous nomadic critical group is likely to be one that sets up camp in the vicinity of, or on top of, the excavated materials. It is unlikely that the group will use the materials for gardening or ornamental purposes, although the materials may be used for building purposes. The exposure pathways for the longer term exposures are:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides.

Probability of Long-term Exposure Following Excavation

Exposures in the longer term arising from the use of excavated materials require that two events occur: that an intrusion occurs and subsequently that a small population resides in the vicinity of or on the contaminated material. The probability at any one time that a community lives on top of contaminated ground can be derived by considering the density of population centres in the surrounding area. In this preliminary assessment, the density has been taken to 1 community per thousand square kilometres (i.e. the linear separation of communities is around 30 km).

The probability of this scenario applying at any time has been taken to be the probability of there being a community (assumed area 0.1 km^2) on top of the contaminated region at that time. Assuming that the cumulative probability that an intrusion event has already occurred is one, this gives the probability of a longer term exposure as:

$$p(\text{longer term exposure}) = 10^{-2} \times 10^{-1} = 10^{-3}$$

Note that the risk calculated using this probability will still be an annual risk, as the long-term nature of the exposures in this scenario means that effective dose *rates* will be calculated.

E8.4.6 Rocket or Weapon Crash

Critical Groups

In this scenario, a rocket, or missile crash (from the nearby Woomera test site) occurs at the repository site. For the purposes of assessment, it is assumed that the projectile is not located, and that the effect of the crash is to remove the cap materials, thus exposing the wastes. The critical group is taken to be a group of children who play in or around the exposed wastes, at some future time after the crash has occurred. They are assumed to spend one hour per day playing at the site.

This choice of critical group assumes that the Woomera test range is no longer used for that purpose. For times shortly after repository closure (e.g. the first 100 years or so), it could be argued that the Woomera test range will still be used for rocket and missile testing, and therefore will not be accessible to the general population. Under these conditions, children playing at the repository location are not a valid choice for the critical group. However, at times further than this into the future, it is difficult to argue with certainty that the Woomera range will still be used in its present capacity. It is therefore considered that the choice of critical group, under the assumption that the Woomera range is no longer used for military purposes, provides a suitably cautious basis for assessment of the radiological effects of a missile or rocket crash.

In a quantitative assessment of doses to nomadic people, the analogous nomadic critical group will be the same as that described above, i.e. children who play at the site of the exposed wastes. The exposure pathways for the rocket crash are:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides.

Probability of a Rocket or Weapon Crash

According to information supplied by Defence, of the weapons fired on the Woomera test site in the last 10 years, about 42 per annum are capable of penetrating to a depth of 5 m. Therefore, it is assumed that about 42 missiles potentially disruptive to the repository hit the ground in the Woomera Instrumented Range (WIR) every year.

If it is assumed that these 42 missiles land at random positions on the test site (an assumption that may not be valid, if the missiles are fired within a limited range of trajectory and velocity values), then an estimate of frequency of impact on the repository can be made. The total area of the Woomera Prohibited Area (WPA) is 127,800 km^2 and the repository has a cross-sectional area of 10^{-2} km^2. If it is further assumed that any strike within 100 m of the repository causes disruption to the wastes, i.e. approximately 9 times the repository disposal area, then the frequency of strike is approximately:

$$f(\text{missile}) = (42 \times 9 \times 10^{-2}) \div (1.28 \times 10^{5}) = 3.0 \times 10^{-5} \text{ disruptions per year}$$

E8.4.7 Aircraft Crash

Critical Groups

In this scenario, an aircraft is assumed to crash at the repository site. In contrast to the situation with the rocket crash, there will be full knowledge of this accident, and so the critical group is taken to be the aircraft recovery team who come to investigate the accident and clear up the debris. It is known that the British Royal Air Force (RAF) can take up to two days to clear the debris, and so the exposure time is taken as 25 hours, corresponding to about two 12-hour working days.

The critical group therefore consists of a recovery team who enter the repository location to clear the debris after the crash, after which they leaves the repository location, and hence are not associated either with settlers or nomadic people. The exposure pathways for the aircraft crash are:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides.

Probability of an Aircraft Crash

The probability of an aircraft crash into the repository can be estimated from consideration of aircraft crash data. According to the Australian authorities, one aircraft crash has occurred at the Woomera test site over the last 10 years.

As with the missile crashes, the best way to proceed is to assume that aircraft crashes occur at random locations on the test site. The target area for which a crash can disturb the repository wastes will be taken to be the same as that for missiles — i.e. any impact within 100 m of the repository location will be considered to disturb the wastes.

From this, the frequency of a disruptive aircraft impact is:

$$f(\text{aircraft}) = (0.1 \times 9 \times 10^{-2}) \div (1.28 \times 10^{5}) \sim 7.0 \times 10^{-8} \text{ crashes/yr}$$

E8.4.8 Agricultural Land Usage Following Climate Change

Critical Groups

In this scenario, it is assumed that the dry and arid climate that currently prevails at the proposed site is replaced by a much wetter climate.

At the present time, the land is dry and unsuitable for agricultural use, with the watertable lying many tens of metres below ground surface. The transition to conditions suitable for agricultural use would therefore require a considerable increase in precipitation levels, sufficient to balance the deficit due to evapotranspiration and raise the level of the watertable. A study has been made of the potential impact of climate change at Maralinga (see Appendix F); however, the study concentrated on the potential for greater erosion of residual contamination by wind or rain.

The study considered the effects of future climate change attributable to the greenhouse effect over a the relatively short timescale of the next 100 years, compared with assessment timescales. In the simulation reported in the study, the average soil moisture content did not change significantly over the period considered. This result suggests there may be limited potential for significant changes in land use over the next 100 years. However, the possibility cannot be ruled out in the longer term, though no view is taken here as to whether such a climate change would occur or not.

The approach taken in this preliminary assessment is to assume that the contaminated material in the disposal structures would be exposed and provide the soil for farming. The critical group is therefore taken to be a farming or subsistence community that sets up a farm in the vicinity of the repository, and derives all of its food produce from this land. Of course, the size of the repository is such that much of the food would be obtained from uncontaminated land, though some would be obtained from the repository footprint. This is taken into account using appropriate 'dilution' factors (see Section E8.5).

In a quantitative assessment of doses to nomadic people, the analogous critical group derived from nomadic people would be a group that sets up camp on or in the region of the contaminated area, and who occupy that position for a period of a few weeks. Of particular interest is the fact that such a group would hunt animals (e.g. rabbits or kangaroos) that had been grazing in the contaminated region. The exposure pathways for the climate change scenario are:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides
- ingestion of plant foodstuffs
- ingestion of animal foodstuffs.

Degree of Belief Associated with Climate Change

Assessing the probability that a transition to a wetter climate state will occur is very difficult. However, computer modelling has been carried out by Commonwealth Scientific and Industrial Research Organisation (CSIRO) (see Appendix F), and this seems to indicate that a transition to a wetter climate state is not certain to occur in the next 10000 years.

The detailed conclusions in Appendix F can be stated as follows:

1. The greenhouse effect will lead to a gradual increase of surface temperature in the Woomera region.
2. The greenhouse effect may lead to a slight increase in rainfall at the Woomera region.
3. Under greenhouse conditions, the frequency of intense periods of rainfall will increase.
4. Soil moisture shows no increasing trend, except in one of the variant scenarios for atmospheric CO_2.
5. Surface winds are unlikely to increase.
6. Over a 10,000 year timescale, climate change may arise from natural climatic variability, though this is difficult (if not impossible) to predict.

With regard to item 6, it can be suggested that wetter climate states could occur, in the same way that the 'Little Ice Age' came and went, but it cannot be stated that such change will definitely occur. Therefore, the degree of belief for this scenario is less than unity.

Owing to the difficulty of making plausible estimates of the degree of belief, the probability of a climate change will be taken as unity. The radiological safety of the facility will be judged on the basis of conditional risks obtained in the assessment calculation. Thus:

$$P(\text{wetter climate}) = 1$$

E8.4.9 Gross Erosion

Critical Groups

In this scenario, it is assumed that the contents of the repository are removed from their current location, and 'smeared' over a larger volume of accessible land. This could arise from the effects of severe wind erosion and rain action, or possibly from climatic change events such as glaciation (though this is unlikely to occur in Central Australia in the next 10,000 years). In any of these cases, the effect would not be seen for many thousands of years into the future.

Because the effect of gross erosion is to place the wastes over a wide area in the accessible environment, the critical group is taken to be the same as that for the climate change scenario described in the previous section, namely a farming or subsistence community that sets up a farm on the contaminated land, and derives all of its food produce from this land.

It should be noted that this scenario differs from the wetter climate scenario as follows. In the wetter climate scenario, it is assumed that the wastes remain largely in situ, whereas in this scenario, the wastes are physically removed (by erosion) and redistributed over the surrounding area.

In a quantitative assessment of doses to nomadic people, the analogous critical group derived from nomadic people would be a group that sets up camp on or in the region of the contaminated area, and who occupy that position for a period of a few weeks. That is, the group is the same as that for the climate change scenario. The exposure pathways for the gross erosion scenario are:

- inhalation of dust
- ingestion of dust
- external irradiation from gamma emitting radionuclides
- ingestion of plant foodstuffs
- ingestion of animal foodstuffs.

Degree of Belief for Gross Erosion

In Section 4.8, it was noted that the frequency of intense periods of rainfall may increase over time. Therefore, it is possible that rain-induced soil erosion rates may increase over time. However, wind-induced erosion is not likely to increase, as surface wind velocities are not expected to increase (item 5 in Section 4.8). Under conditions of increased rainfall, it has been suggested that a representative rate of erosion at the site would be of order 1 mm/yr (S Veitch, Bureau of Rural Science, pers. comm. January 2002). Thus, it might be expected that the upper materials overlying the repository could be eroded away in as little as 5000 years (though possibly longer, if rainfall rates remain as they are at the present day).

As for the transition to a wetter climate state, it will be assumed that gross erosion (by whatever means) will eventually remove the repository contents and 'smear' them over an area of the accessible environment, so that the degree of belief for this scenario is taken to be unity. The difficulty in this case is deciding on what timescale this will occur. In interpreting the assessment results, it will be assumed that at least 5000 years passes before this situation arises. Further research may be required to determine if such erosion could occur before this time.

$P(\text{gross erosion}) = 1$

E8.4.10 Site Flooding

Critical Groups

A further process that is often considered in assessments of near-surface waste burial disposal structures is bathtubbing. This occurs if water builds up within the disposal structures (for example because natural or engineered drainage features lose their efficiency) and results in contamination of surface soils and sediments. To occur it requires an impermeable barrier within or around the disposal structures.

The approach adopted is to assume that surface soils become contaminated to a level equal to that in repository porewater. Again, the critical group is taken to be a farming or subsistence community that sets up a farm in the vicinity of the repository, and derives all of its food produce from the repository footprint and surrounding land.

In a quantitative assessment of doses to nomadic people, the analogous critical group derived from nomadic people would be a group that sets up camp on or in the region of the contaminated area, and who occupy that position for a period of a few weeks. That is, the group is the same as that for the climate change scenario. The exposure pathways for the bathtubbing scenario are:

- inhalation of dust
- ingestion of dust

- external irradiation from gamma emitting radionuclides
- ingestion of plant foodstuffs
- ingestion of animal foodstuffs.

Degree of Belief for Site Flooding

Bathtubbing is most likely to occur if the transition to a wetter climate state occurs, though the phenomenon cannot be ruled out in the absence of a wetter climate (depending on the local hydrogeology, etc). It would also require a failure of the drainage systems in place at the repository. These are difficult to estimate and so cautiously (as site flooding is extremely unlikely to occur in practice), as for the wetter climate state and gross erosion scenarios, the probability of occurrence will be taken as unity. The radiological safety of the facility will be judged on the basis of conditional risks obtained in the assessment calculation.

$$P(\text{bathtubbing}) = 1$$

E8.4.11 Consumption of Contaminated Waters

Critical Groups

In this scenario, it is assumed that a well drilled through the repository footprint and the extracted water is used for drinking purposes. It is of course questionable as to whether such waters would be potable, and the scenario can only arise in a wetter climate state. Nevertheless, it is possible that a farming community may wish to set up such a well, and it is likely that the extracted waters would be used for many purposes, including irrigation, domestic usage and as drinking water for animals. In this preliminary assessment, only drinking of such waters will be considered.

Note that this scenario is specifically concerned with the removal of water from the repository itself. The removal of waters from the regional aquifer underlying the repository is examined in Section E8.9.

The critical group for nomadic people is taken to be the same as that for settlers described above, though the water may not necessarily be obtained through well drilling. The exposure pathway for the contaminated well water scenario:

- ingestion of contaminated water.

Probability of Consumption of Contaminated Waters

The probability of a well intersecting the repository can be obtained from historical knowledge of the frequency with which wells are drilled in the surrounding area (if such information exists). For the purpose of this preliminary assessment, it will be assumed that such a well would be drilled by a farmer who has set up a farm at the repository site during wetter climate conditions. If it is assumed that the farmer owns 1 km^2 of land and definitely drills a well somewhere on his land once every 10 years (a somewhat pessimistic assumption), then the frequency of well drilling on contaminated land is:

$$f(\text{well}) = 10^3 / (10^6 \times 10) = 10^{-4} \text{ wells/yr.}$$

It should be noted that this scenario can only occur during a wetter climate (in order for the watertable to be sufficiently close to the ground surface to make well drilling practical), and so this estimate of well-drilling frequency is also contingent on the occurrence of climate change. The estimate is therefore somewhat pessimistic.

E8.4.12 Effects of Gas

The scenarios, approach and results obtained from the gas assessment are presented in Section E8.8.

E8.5 Radiological Dose Equations

In this Section, equations are presented for evaluating radiological doses via the various exposure pathways identified for each scenario in Section E8.4. The basis of the dose equations are very simple. For external doses, the form of the dose equations are:

Effective dose rate (Sv/yr) = Gamma dose rate (Sv/hr) $\times$ *Exposure time (hr/yr)*

For internal doses, the corresponding expression is:

Effective dose rate (Sv/yr) = Intake per unit time (Bq/yr) $\times$ *Dose-per-unit-uptake (Sv/Bq)*

The starting point for the dose calculations is the calculation of radionuclide concentrations in the repository. In the homogeneous model (i.e. the radionuclides are assumed to be distributed uniformly throughout the repository volume), the concentration is simply the radionuclide inventory divided by the mass of repository materials:

$$C_i = \frac{N_i}{\rho V}$$

where C_i (Bq/kg) is the mass concentration of radionuclide *i*
N_i (Bq) is the current inventory of radionuclide *i*
ρ (kg/m^3) is density of repository materials
V (m^3) is volume of repository materials

To calculate concentrations as a function of time, the inventory is decayed forwards in time using Bateman's equations and their solution:

$$\frac{dN_i}{dt} = \lambda_i (N_{i-1} - N_i)$$

where N_i (Bq) is the activity of radionuclide *i*
λ_i (yr^{-1}) is the decay constant of radionuclide *i*
t (yr) is the time under consideration

where the equations are written in terms of activity units (Becquerels). The calculation of concentrations requires a knowledge of the repository dimensions and material properties, the radionuclide inventory and the radionuclide half-lives. These are given in Tables E8.3, E8.1 and E8.6, respectively. Table E8.6 contains all of the radionuclide-specific parameter values that are used in this assessment.

For reference, the parameter values used in these equations to undertake the dose and risk assessments for the settler critical groups are set out in tables, as follows:

Table E8.1	Proposed inventory of radionuclides for the national repository
Table E8.3	Parameter values for the proposed national repository
Table E8.6	Radionuclide-specific parameter values
Table E8.7	Parameter values for plant and animal consumption
Table E8.8	Parameter values for the borehole core examination scenario
Table E8.9	Parameter values for the bulk excavation scenario
Table E8.10	Parameter values for the road construction and archaeological dig scenarios
Table E8.11	Parameter values for the exposure to future inhabitants scenario
Table E8.12	Parameter values for the rocket crash scenario
Table E8.13	Parameter values for the aircraft crash scenario
Table E8.14	Parameter values for the wetter climate scenario
Table E8.15	Parameter values for the gross erosion scenario
Table E8.16	Parameter values for the site flooding (bathtubbing) scenario.

TABLE E8.6 Radionuclide-specific parameter values

Nuclide	$T_{0.5}$	K_D	H_1	H_2	H_3	H_4	$\eta_{pasture}$	η_{green}	η_{root}	η_{grain}
H-3	1.24E+01	0.00E+00	0.00E+00	1.80E-11	1.80E-11	0.00E+00	3.00E+01	3.00E+01	3.00E+01	3.00E+01
^{14}C	5.73E+03	0.00E+00	0.00E+00	6.50E-12	5.80E-10	5.88E-23	1.30E-01	2.20E-01	1.40E+00	1.60E-01
Sr-90	2.91E+01	2.00E-02	1.58E-19	1.60E-07	2.80E-08	3.46E-21	2.20E-01	7.00E-02	1.40E-01	1.40E-01
Fe-55	2.70E+00	8.10E-01	1.58E-16	7.70E-10	3.30E-10	0.00E+00	4.00E-04	4.00E-04	4.00E-04	4.00E-04
Co-60	5.27E+00	1.30E+00	2.50E-13	3.10E-08	3.40E-09	8.25E-17	1.20E-02	1.50E-02	2.10E-02	5.40E-03
Ni-63	9.60E+01	3.00E-01	0.00E+00	1.30E-09	1.50E-10	0.00E+00	8.00E-03	1.40E-02	8.60E-02	1.00E-02
Cd-109	1.27E+00	4.00E-02	0.00E+00	8.10E-09	2.00E-09	6.54E-20	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Sb-125	2.77E+00	1.50E-01	0.00E+00	1.20E-08	1.10E-09	1.22E-17	1.00E-02	1.00E-02	1.00E-02	1.00E-02
I-129	1.57E+07	4.50E-03	2.30E-15	3.60E-08	1.10E-07	5.11E-20	2.00E-02	3.50E-02	2.20E-01	2.50E-02
Ba-133	1.07E+01	2.00E-02	0.00E+00	1.00E-08	1.50E-09	9.75E-18	3.00E-02	3.00E-02	3.00E-02	3.00E-02
Cs-134	2.06E+00	4.40E+00	0.00E+00	2.00E-08	1.90E-08	4.77E-17	2.60E-02	1.10E-02	1.50E-02	1.70E-02
Cs-137	3.00E+01	4.40E+00	6.79E-14	3.90E-08	1.30E-08	1.71E-17	2.60E-02	1.10E-02	1.50E-02	1.70E-02
Pm-147	2.62E+00	8.10E+00	0.00E+00	5.00E-09	2.60E-10	2.30E-22	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Eu-152	1.33E+01	8.10E+00	1.25E-13	4.20E-08	1.40E-09	3.50E-17	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Eu-154	8.80E+00	8.10E+00	1.34E-13	5.30E-08	2.00E-09	3.89E-17	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Ho-166	4.96E+00	8.10E+00	0.00E+00	6.90E-09	3.20E-10	8.66E-19	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Tl-204	3.78E+00	1.50E-01	0.00E+00	3.90E-09	1.20E-09	2.08E-20	3.00E-02	3.00E-02	3.00E-02	3.00E-02
Bi-207	3.80E+01	1.50E-01	0.00E+00	5.60E-09	1.30E-09	4.73E-17	2.80E-03	4.90E-03	3.00E-02	3.50E-03
Po-210	3.79E-01	4.00E-01	1.03E-18	4.30E-06	1.20E-06	2.64E-22	2.40E-04	4.20E-04	2.60E-03	3.00E-04
Pb-210	2.23E+01	1.60E+01	4.49E-16	5.60E-06	6.90E-07	1.06E-20	4.00E-04	7.00E-04	4.30E-03	5.00E-04
Ra-226	1.60E+03	3.60E+01	1.83E-13	9.50E-06	2.80E-07	5.68E-17	2.40E-03	4.20E-03	2.60E-02	3.00E-03
Ra-228	5.75E+00	3.60E+01	1.06E-13	1.60E-05	6.90E-07	3.03E-17	2.40E-03	4.20E-03	2.60E-02	3.00E-03
Ac-227	2.18E+01	1.50E+00	4.67E-14	5.50E-04	1.10E-06	1.58E-20	1.60E-05	2.80E-05	1.70E-04	2.00E-05
Th-228	1.91E+00	3.30E+00	1.50E-13	4.00E-05	7.20E-08	3.84E-20	2.40E-05	4.20E-05	2.90E-05	1.10E-03
Th-229	7.34E+03	3.30E+00	3.71E-14	2.40E-04	4.90E-07	1.55E-18	2.40E-05	4.20E-05	2.90E-05	1.10E-03
Th-230	7.70E+04	3.30E+00	1.48E-16	1.00E-04	2.10E-07	5.73E-21	2.40E-05	4.20E-05	2.90E-05	1.10E-03
Th-232	1.41E+10	3.30E+00	1.25E-16	1.10E-04	2.30E-07	2.44E-21	2.40E-05	4.20E-05	2.90E-05	1.10E-03
Pa-231	3.28E+04	1.80E+00	5.52E-15	1.40E-04	7.10E-07	9.44E-19	2.40E-05	4.20E-05	2.90E-05	1.10E-03
U-233	1.59E+05	1.20E-02	1.27E-16	9.60E-06	5.10E-08	6.77E-21	1.20E-03	2.10E-03	1.30E-02	1.50E-03
U-234	2.45E+05	1.20E-02	1.62E-16	9.40E-06	4.90E-08	1.84E-21	1.20E-03	2.10E-03	1.30E-02	1.50E-03
U-235	7.04E+08	1.20E-02	1.88E-14	8.50E-06	4.70E-08	3.53E-18	1.20E-03	2.10E-03	1.30E-02	1.50E-03
U-236	2.34E+07	1.20E-02	1.46E-16	8.70E-06	4.70E-08	9.51E-22	1.20E-03	2.10E-03	1.30E-02	1.50E-03
U-238	4.47E+09	1.20E-02	2.93E-15	8.00E-06	4.50E-08	4.26E-22	1.20E-03	2.10E-03	1.30E-02	1.50E-03
Np-237	2.14E+06	2.50E-02	2.73E-14	5.00E-05	1.10E-07	3.72E-19	2.40E-03	2.80E-03	2.30E-03	3.00E-03
Pu-238	8.77E+01	1.20E+00	1.69E-16	1.10E-04	2.30E-07	6.24E-22	1.60E-05	2.80E-05	1.70E-04	2.00E-05
Pu-239	6.54E+03	1.20E+00	7.47E-17	1.20E-04	2.50E-07	6.02E-22	1.60E-05	2.80E-05	1.70E-04	2.00E-05
Pu-240	1.44E+01	1.20E+00	1.57E-16	1.20E-04	2.50E-07	2.84E-23	1.60E-05	2.80E-05	1.70E-04	2.00E-05
Pu-244	8.26E+07	1.20E+00	0.00E+00	1.10E-04	2.40E-07	1.02E-17	1.60E-05	2.80E-05	1.70E-04	2.00E-05
Am-241	4.32E+02	9.90E-01	3.03E-15	9.60E-05	2.00E-07	1.99E-19	1.60E-05	2.80E-05	1.70E-04	2.00E-05
Am-243	7.38E+03	9.90E-01	2.41E-14	9.60E-05	2.00E-07	6.65E-19	1.60E-05	2.80E-05	1.70E-04	2.00E-05
Cm-244	1.81E+01	1.80E+01	0.00E+00	5.70E-05	1.20E-07	4.79E-22	1.60E-05	2.80E-05	1.70E-04	2.00E-05
Cm-248	3.39E+05	1.80E+01	0.00E+00	3.60E-04	7.70E-07	3.35E-22	1.60E-05	2.80E-05	1.70E-04	2.00E-05
Cf-252	2.64E+00	1.80E+01	0.00E+00	2.00E-05	9.00E-08	7.28E-22	1.60E-05	2.80E-05	1.70E-04	2.00E-05

Nuclide[(1)]	TF_{cow}	TF_{sheep}	TF_{kang}	TF_{rab}	Nuclide	TF_{cow}	TF_{sheep}	TF_{kang}	TF_{rab}
H-3	2.89E-02	4.12E-01	4.12E-01	6.87E+00	**Ac-227**	2.00E-05	8.00E-05	8.00E-05	1.33E-03
^{14}C	7.50E-02	4.90E-01	4.90E-01	8.17E+00	**Th-228**	3.00E-05	1.00E-04	1.00E-04	1.67E-03
Sr-90	1.60E-02	3.00E-02	3.00E-02	5.00E-01	**Th-229**	3.00E-05	1.00E-04	1.00E-04	1.67E-03
Fe-55	2.00E-02	7.30E-02	7.30E-02	1.22E+00	**Th-230**	3.00E-05	1.00E-04	1.00E-04	1.67E-03
Co-60	3.00E-04	6.20E-02	6.20E-02	1.03E+00	**Th-232**	3.00E-05	1.00E-04	1.00E-04	1.67E-03
Ni-63	1.00E-02	2.00E-02	2.00E-02	3.33E-01	**Pa-231**	1.00E-03	1.00E-03	1.00E-03	1.67E-02
Cd-109	4.00E-04	4.00E-03	4.00E-03	6.67E-02	**U-233**	2.00E-04	1.00E-03	1.00E-03	1.67E-02
Sb-125	4.00E-05	4.00E-04	4.00E-04	6.67E-03	**U-234**	2.00E-04	1.00E-03	1.00E-03	1.67E-02
I-129	4.00E-03	4.00E-02	4.00E-02	6.67E-01	**U-235**	2.00E-04	1.00E-03	1.00E-03	1.67E-02
Ba-133	2.00E-04	2.00E-03	2.00E-03	3.33E-02	**U-236**	2.00E-04	1.00E-03	1.00E-03	1.67E-02
Cs-134	1.20E-01	6.00E-01	6.00E-01	1.00E+01	**U-238**	2.00E-04	1.00E-03	1.00E-03	1.67E-02
Cs-137	1.20E-01	6.00E-01	6.00E-01	1.00E+01	**Np-237**	2.00E-05	1.00E-04	1.00E-04	1.67E-03
Pm-147	2.00E-05	2.00E-04	2.00E-04	3.33E-03	**Pu-238**	3.00E-06	1.00E-05	1.00E-05	1.67E-04
Eu-152	2.00E-05	2.00E-04	2.00E-04	3.33E-03	**Pu-239**	3.00E-06	1.00E-05	1.00E-05	1.67E-04
Eu-154	2.00E-05	2.00E-04	2.00E-04	3.33E-03	**Pu-240**	3.00E-06	1.00E-05	1.00E-05	1.67E-04
Eu-155	2.00E-05	2.00E-04	2.00E-04	3.33E-03	**Pu-244**	3.00E-06	1.00E-05	1.00E-05	1.67E-04
Tl-204	4.00E-05	4.00E-04	4.00E-04	6.67E-03	**Am-241**	2.00E-05	8.00E-05	8.00E-05	1.33E-03
Bi-207	2.00E-04	2.00E-03	2.00E-03	3.33E-02	**Am-243**	2.00E-05	8.00E-05	8.00E-05	1.33E-03
Po-210	2.00E-02	1.50E-01	1.50E-01	2.50E+00	**Cm-244**	2.00E-05	8.00E-05	8.00E-05	1.33E-03
Pb-210	7.00E-03	3.00E-02	3.00E-02	5.00E-01	**Cm-248**	2.00E-05	8.00E-05	8.00E-05	1.33E-03
Ra-226	3.00E-04	2.00E-03	2.00E-03	3.33E-02	**Cf-252**	2.00E-05	8.00E-05	8.00E-05	1.33E-03
Ra-228	3.00E-04	2.00E-03	2.00E-03	3.33E-02					

$T_{0.5}$ Radionuclide half-life (yr) – note that the decay constant $\lambda = \ln(2)/T_{0.5}$
K_D Sorption coefficient ($m^{3/}kg$)
H_1 External dose rate (Sv/h) at 1 m from a point source of 1 Bq
H_2 Committed effective dose per unit uptake by inhalation (Sv/Bq)
H_3 Committed effective dose per unit uptake by ingestion (Sv/Bq)
H_4 External dose rate (Sv/h) from an infinite plane 1 m above an infinite thick slab source of strength 1 Bq/kg
TF_{xxxx} Transfer factors from animal foodstuffs to animal xxxx (d/kg or d/L)
η_{xxxx} Soil to plant concentration ratio for plant type xxxx
(1) The transfer factors in this part of the table refer to transfer to animal muscle.

TABLE E8.7 Parameter values for plant and animal consumption

Quantity	Units	Settlers	Nomads
Consumption rate for green vegetables	kg/yr	70	24
Consumption rate for root vegetables	kg/yr	70	
Consumption rate for grain products	kg/yr	50	
Consumption rate for fruit	kg/yr	110	30
Consumption rate for sheep meat	kg/yr	20	
Consumption rate for beef	kg/yr	70	
Consumption rate for kangaroo meat	kg/yr		205
Consumption rate for rabbit meat	kg/yr		13
Quantity	**Units**	**Value**	
Forage intake rate for cows	kg/yr	75	
Forage intake rate for sheep	kg/yr	13	
Forage intake rate for kangaroos	kg/yr	13	

Quantity	Units	Value
Forage intake rate for rabbits	kg/yr	1.6
Soil intake rate for cows	kg/yr	0.75
Soil intake rate for sheep	kg/yr	0.13
Soil intake rate for kangaroos	kg/yr	0.13
Soil intake rate for rabbits	kg/yr	0.016
Water intake rate for cows	L/yr	40
Water intake rate for sheep	L/yr	4
Water intake rate for kangaroos	L/yr	4
Water intake rate for rabbits	L/yr	0.24

Source of consumption rates: ICRP 1975

TABLE E8.8 Parameter values for the borehole core examination scenario

Parameter	Symbol	Units	Value
Dilution factor(1)	f		1.00
Distance from sample	d	m	1
Time of examination(2)	T_{exam}	h	1
Mass of sample	M_{sample}	kg	50
Number of samples(3)	n		1
Rate of dust Ingestion	m	kg/h	1.25E-05
Dust load(4)	μ	kg/m^3	1E-06
Breathing rate(4)	B	m^3/h	1.2

(1) The dilution factor assumes that the borehole cores are extracted from undiluted repository materials.
(2) It was assumed that a typical borehole core would be examined for no more than 1 hour, and at a distance of no less than 1 m.
(3) The number of samples examined was set at one. In practice, it is unlikely that more than one or two cores would be examined from the same location.
(4) The dust load corresponds to a moderately dust working environment, and the breathing rate is appropriate to moderate physical exertion.

TABLE E8.9 Parameter values for the bulk excavation scenario

Parameter	Symbol	Units	Value
Dilution factor(1)	f		0.5
Time of examination(2)	T_{exam}	h	8.0
Rate of dust ingestion	m	kg/h	1.25E-05
Dust load(3)	μ	kg/m^3	5E-06
Breathing rate(3)	B	m^3/h	1.2

(1) The dilution factor assumes that some dilution of repository excavated materials will occur, due to mixing with uncontaminated materials.
(2) It was assumed that excavation occurs for one working day, i.e. a total of around 8 hours.
(3) The dust load corresponds to a very dusty working environment, and the breathing rate is appropriate to moderate physical exertion.

TABLE E8.10 Parameter values for the road construction and archaeological dig scenarios

Parameter	Symbol	Units	Value for road building	Value for archaeological dig
Dilution factor(1)	f		0.7	0.5
Time of excavation(2)	T_{excav}	h	50	400
Rate of dust ingestion	m	kg/h	1.25E-05	1.25E-05
Dust load(3)	μ	kg/m^3	1.00E-06	5.00E-06
Breathing rate(4)	B	m^3/h	1.2	1.2

(1) The dilution factors were chosen under the assumption that road builders would tend to mix cap materials and waste materials as they work, whereas archaeologists would excavate either directly into wastes or directly into uncontaminated materials.
(2) The times of excavation were set as cautious maxima for the likely times of contact with contaminated materials.
(3) The dust load for road builders is appropriate to a moderately dusty environment. (In the case of archaeologists, the dust load is set higher to reflect the closer proximity (e.g. on bended knees) to contaminated materials.)
(4) The breathing rate is appropriate to moderate physical activity.

TABLE E8.11 Parameter values for the exposure to future inhabitants scenario

Parameter	Symbol	Units	Settlers	Nomads
Occupancy of contaminated area	O	–	0.33(1)	0.66(2)
Dilution factor(3)	f	–	0.4	0.4
Dust load(4)	μ	kg/m^3	1.0E-07	1.0E-07
Breathing rate(5)	B	m^3/h	1.2	1.2
Rate of spoil consumption(6)	M_{spoil}	kg/yr	0.035	0.9

(1) The occupancy factor for settlers corresponds to a critical group that spends 8 hours per day in contact with contaminated materials, for example a family who spend their days tending their land.
(2) The occupancy factor for nomads assumes that they spend all of their waking hours in contact with the contaminated materials, i.e. 16 hours per day.
(3) The dilution factor assumes that a reasonable degree of dilution would occur if contaminated materials were employed for agricultural purposes, for example, used as topsoil materials which subsequently mixed with deeper layers.
(4) The dust load is appropriate to that found in environments where soil materials are not disturbed to any great extent.
(5) The breathing rate corresponds is appropriate to a person who undergoes a moderate degree of exertion.
(6) The rate of spoil consumption for nomads is based on a daily consumption rate of 2.5 g/day, arising from cooking practices adopted.

TABLE E8.12 Parameter values for the rocket crash scenario

Parameter	Symbol	Units	Settlers	Nomads
Dilution factor(1)	f		1.00E+00	1.00E+00
Time of exposure(2)	T_{exp}	h	3.65E+02	4.2E+01
Rate of dust ingestion	m	kg/h	1.25E-05	1.25E-05
Dust load(3)	μ	kg/m^3	1.00E-06	1.00E-06
Breathing rate(4)	B	m^3/h	1.20E+00	1.20E+00

(1) The dilution factor was chosen under the assumption that children are directly exposed to the wastes in the repository.
(2) The times of exposure were set on the assumption that children play at the repository site for one hour per day. For settlers, this is 1 hour per day through the year. For nomads, it is 1 hour per day for an assumed stay of 6 weeks.
(3) The dust load is appropriate to a moderately dusty environment.
(4) The breathing rate is appropriate to moderate physical activity.

TABLE E8.13 Parameter values for the aircraft crash scenario

Parameter	Symbol	Units	Value
Dilution factor(1)	f		1.00E+00
Time of exposure(2)	T_{exp}	h	25
Rate of dust ingestion	m	kg/h	1.25E-05
Dust load(3)	μ	kg/m^3	1.00E-06
Breathing rate(4)	B	m^3/h	1.20E+00

(1) The dilution factor was chosen under the assumption that recovery workers are directly exposed to the wastes in the repository.
(2) The time of exposure was set on the assumption that recovery workers require 25 hours to complete clean-up activities.
(3) The dust load is appropriate to a moderately dusty environment.
(4) The breathing rate is appropriate to moderate physical activity.

TABLE E8.14 Parameter values for the wetter climate scenario

Parameter	Symbol	Units	Settlers	Nomads
Dilution factor(1)	f		1.00E-02	1.00E-02
Time of exposure(2)	T_{exp}	h/yr	2.90E+03	6.72E+02
Rate of dust ingestion	m	kg/h	1.25E-05	1.6E-04
Dust load(3)	μ	kg/m^3	1.00E-06	1.00E-06
Breathing rate(4)	B	m^3/h	1.20E+00	1.20E+00

(1) The dilution factor was chosen under the assumption that arable and grazing land occupies 1 km^2 and that the repository footprint is 10000 m^2.
(2) The times of exposure were set on the assumption that settler workers spend up to 8 hours per day in the field, and that nomads spend all of their waking hours in the field, for 6 weeks.
(3) The dust load is appropriate to a moderately dusty environment.
(4) The breathing rate is appropriate to moderate physical activity.

TABLE E8.15 Parameter values for the gross erosion scenario

Parameter	Symbol	Units	Settlers	Nomads
Dilution factor(1)	f		1.00E-03	1.00E-03
Time of exposure(2)	T_{exp}	h/yr	2.90E+03	6.72E+02
Rate of dust ingestion	m	kg/h	1.25E-05	1.6E-04
Dust load(3)	μ	kg/m^3	1.00E-06	1.00E-06
Breathing rate(4)	B	m^3/h	1.20E+00	1.20E+00

(1) The dilution factor was chosen under the assumption that the repository contents are eroded over an area of 10 km^2 and to a depth of 1 m.
(2) The times of exposure were set on the assumption that settler workers spend up to 8 hours per day in the field, and that nomads spend all of their waking hours in the field, for 6 weeks.
(3) The dust load is appropriate to a moderately dusty environment.
(4) The breathing rate is appropriate to moderate physical activity.

TABLE E8.16 Parameter values for the site flooding (bathtubbing) scenario

Parameter	Symbol	Units	Settlers	Nomads
Dilution factor(1)	f		7.00E-03	7.00E-03
Time of exposure(2)	T_{exp}	h/yr	2.90E+03	6.72E+02
Rate of dust ingestion	m	kg/h	1.25E-05	1.6E-04
Dust load(3)	μ	kg/m^3	1.00E-06	1.00E-06
Breathing rate(4)	B	m^3/h	1.20E+00	1.20E+00

(1) The dilution factor was chosen under the assumption that arable and grazing land occupies 1 km^2 and that the repository footprint is 10,000 m^2. In addition, upward leaching to the ground surface would introduce an extra dilution of around 0.7.
(2) The times of exposure was set on the assumption that settler workers spend up to 8 hours per day in the field, and that nomads spend all of their waking hours in the field, for 6 weeks.
(3) The dust load is appropriate to a moderately dusty environment.
(4) The breathing rate is appropriate to moderate physical activity.

Radionuclide-specific parameters relating to the behaviour of radionuclides in the biosphere can be obtained from the relevant IAEA handbook (1994). Dose-per-unit-uptake factors were obtained from ICRP 72 (1996), and, where required, basic human physiological data was obtained from ICRP 23 (1975). National consumption rates are obtained from (NHMRC 2000), which provides information both for Aboriginal communities and overall averages for Australia.

The following sections provide dose equations for each of the scenarios considered.

E8.5.1 Borehole Drilling

The concentration in the extracted sample may be less than the concentration in the disposal structures, however, because of mixing with uncontaminated material also extracted. This is represented by:

$$S = fC \tag{5.1}$$

where S (Bq/kg) is the concentration in the sample
f is the degree of mixing (between 0 and 1)
C (Bq/kg) is the concentration of radionuclides in the waste.

Exposure will arise from handling and examination of extracted samples. Three routes of exposure are identified as being of potential significance:

- external irradiation
- inhalation of contaminated dust
- ingestion of contaminated dust.

These are addressed below. Throughout, the equations are developed for a single radionuclide and it is assumed that there are *n* extracted samples that are handled and examined by a particular individual.

External Exposure

For this exposure route, each sample is treated as a point source. Thus, the effective dose is given by:

$$H_{ext} = \frac{nT_{exam}SMH_1}{d^2} \tag{5.2}$$

where H_{ext} (Sv) is the effective dose due to external exposure
T_{exam} (h) is the time for which each sample is examined
H_1 is the effective dose rate (Sv/h) at a distance of 1 m from a source of strength 1 Bq
S (Bq/kg) is the radionuclide concentration in the sample

M	(kg) is the mass of the sample
d	(m) is the average distance of the individual from the sample.

Ingestion of Contaminated Dust

In this case, the equation is:

$$H_{ing} = nT_{exam}SmH_2 \qquad (5.3)$$

where
- H_{ing} (Sv) is the effective dose from ingestion of contaminated dust
- m (kg/h) is the rate of dust ingestion during sample examination
- H_2 (Sv/Bq) is the committed effective dose per unit intake by ingestion.

Other quantities are as defined above.

Inhalation of Contaminated Dust

In this case, the equation is

$$H_{inh} = nT_{exam}S\mu BH_3 \qquad (5.4)$$

where
- H_{inh} (Sv) is the effective dose from inhalation of contaminated dust
- μ (kg/m^3) is the dust load in the respiratory zone of the exposed individual arising from the contaminated sample
- B (m^3/h) is the breathing rate of the exposed individual
- H_3 (Sv/Bq) is the committed effective dose per unit intake by inhalation.

E8.5.2 Bulk Excavation

In this subsection, doses received by the workers undertaking construction or excavation activities are addressed. With appropriate data, the model described below is applicable to both the bulk excavation, road construction and archaeological dig scenarios. In this case, consideration has to be given to external exposure, ingestion of dust and inhalation of dust.

The concentration in the excavated materials may be less than the concentration in the disposal structures, however, because of mixing with uncontaminated material also excavated. This is represented by an equation of the form of Equation 5.1. As in the case of borehole samples, the relevant radionuclide concentrations, *S*, are those occurring at the time of intrusion. However, it should be noted that the dilution factor *f* for bulk excavation can differ from that for samples extracted from boreholes. Thus, the values of *S* for bulk excavation may differ from those used for borehole samples.

External Exposure

In this case, the relevant equation is:

$$H_{ext} = T_{excav}H_4S \qquad (5.5)$$

where
- H_{ext} (Sv) is the effective dose due to external exposure
- T_{excav} (h) is the time over which contaminated material is exposed during excavation
- H_4 is the effective dose rate (Sv/h) 1 m above an infinite thick slab source of strength 1 Bq/kg
- S (Bq/kg) is the radionuclide concentration in the sample.

Ingestion of Dust

In this case, the relevant equation is:

$$H_{ing} = T_{excav} S m H_2 \tag{5.6}$$

where H_{ing} (Sv) is the effective dose from ingestion of contaminated dust
m (kg/h) is the rate of dust ingestion during excavation
H_2 (Sv/Bq) is the committed effective dose per unit intake by ingestion.

Inhalation of Dust

In this case, the relevant equation is

$$H_{inh} = T_{excav} S \mu B H_3 \tag{5.7}$$

where H_{inh} (Sv) is the effective dose from inhalation of contaminated dust
μ (kg/m^3) is the dust load in the respiratory zone of the exposed individual arising from the contaminated sample
B (m^3/h) is the breathing rate of the exposed individual
H_3 (Sv/Bq) is the committed effective dose per unit intake by inhalation.

E8.5.3 Road Building and Archaeology

The dose equations for the road building and archaeology scenarios are as given in Section E8.5.2.

E8.5.4 Long-term Exposures Due to Excavation

This scenario relates to the exposure of future inhabitants in the region of the site as a result of exposure to contaminated spoil left in the region of the disposal structures after some previous intrusion event.

The concentration in the excavated spoil may be less than the concentration in the disposal structures, however, because of mixing with uncontaminated material also excavated. This is represented by an equation of the form of Equation 5.1. Note that the dilution factor *f* may not be the same as for excavation workers (Section E8.5.2), as the excavated spoil may be mixed with other spoil from uncontaminated sources. However, the value of *f* used here would not normally be larger than that used for excavation workers.

In this case, as before, three pathways of exposure are considered. These relate to:

- external irradiation
- inhalation of resuspended material
- ingestion of spoil.

The equations used are set out below.

External Irradiation

In this case, the equation is:

$$H_{ext} = S O k_1 \tag{5.8}$$

where H_{ext} (Sv/yr) is the effective dose rate due to external irradiation
O is the fractional occupancy of the contaminated area
k_1 is the external dose rate (Sv/yr) to an individual present on spoil contaminated at a concentration of 1 Bq/kg.

Inhalation of Resuspended Material

In this case, the equation is:

$$H_{inh} = \mu S_s B O H_3 \quad (5.9)$$

where H_{inh} (Sv/yr) is the effective dose rate due to inhalation
μ (kg/m^3) is the dust load in air derived from local spoil
S_S (Bq/kg) is the radionuclide concentration on solids
B (m^3/yr) is the breathing rate
H_3 (Sv/Bq) is the committed effective dose per unit intake by inhalation.

If the spoil has a water filled porosity, then partitioning of radionuclides between the pore water and the solid is possible. This may be represented:

$$\rho_d S = \phi S_{sol} + \rho_d S_s \quad (5.10)$$

where ρ_d (kg/m^3) is the dry bulk density of the spoil
ϕ is the water-filled porosity of the spoil
S_{sol} (Bq/m^3) is the radionuclide concentration in water in the spoil.

Also

$$S_s = K_d S_{sol} \quad (5.11)$$

where K_d (m^3/kg) is the equilibrium distribution coefficient. This is defined as the ratio of the amount of a radionuclide sorbed to the soil and the amount in solution at equilibrium.

Thus, it follows that

$$S_s = \frac{\rho_d K_d S}{\phi + \rho_d K_d} \quad (5.12)$$

In practice, the pore space in the spoil may not be water filled at the proposed disposal site. However, this assumption will have negligible impact on the calculated results since radionuclides of interest partition strongly on to the solid.

Ingestion of Spoil

In this case, the relevant equation is:

$$H_{spoil} = M_{spoil} S H_2 \quad (5.13)$$

where H_{spoil} (Sv/yr) is the effective dose rate due to spoil consumption
M_{spoil} (kg/yr) is the rate of spoil consumption
H_2 (Sv/Bq) is the committed effective dose per unit intake by ingestion.

E8.5.5 Rocket and Weapon Crashes

The exposure pathways and effective dose equations for the rocket or weapon crash scenario are similar to those for excavation workers, presented in Section E8.5.2.

E8.5.6 Aircraft Crashes

The exposure pathways and effective dose equations for the aircraft crash scenario are similar to those for excavation workers, presented in Section E8.5.2.

E8.5.7 Wetter Climate

In the wetter climate state, two additional exposure pathways are introduced, namely:

- ingestion of plant foodstuffs
- ingestion of animal foodstuffs.

The dose equations for these two pathways are given below.

Consumption of Plant Produce

In this case, the basic equation is:

$$H_{food} = M_{food} C_{food} H_2 \quad (5.14)$$

where H_{food} (Sv/yr) is the annual effective dose from ingestion of a specific contaminated plant product
M_{food} (kg/yr) is the rate of consumption of that contaminated foodstuff, averaged over the year of interest
C_{food} (Bq/kg) is the average concentration of the radionuclide in the foodstuff, as ingested
H_2 (Sv/Bq) is the committed effective dose per unit intake value for the radionuclide.

Values of H_{food} should be summed over all the radionuclides and plant foodstuffs of relevance.

Radionuclide concentrations in foodstuffs are estimated from radionuclide concentrations in soils. In this approach, radionuclide concentrations in plants are estimated by use of a plant:soil concentration ratio. Thus:

$$C_{plant} = \eta_{plant} C_{soil} \quad (5.15)$$

where C_{plant} (Bq/kg fresh weight) is the radionuclide concentration in the plant
η_{plant} (kg dry weight soil per kg fresh weight plant) is the plant:soil concentration ratio
C_{soil} (Bq/kg dry weight) is the radionuclide concentration in soil.

Consumption of Animal Products

As with plants, the basic equation is:

$$H_{food} = M_{food} C_{food} H_2 \quad (5.16)$$

where H_{food} (Sv/yr) is the annual effective dose from ingestion of a specific contaminated animal product

M_{food}	(kg/yr) is the rate of consumption of that contaminated foodstuff, averaged over the year of interest
C_{food}	(Bq/kg) is the average concentration of the radionuclide in the foodstuff, as ingested
H_2	(Sv/Bq) is the committed effective dose per unit intake value for the radionuclide.

However, in the case of animal products, the concentration in the food is given by:

$$C_{food} = (I_p \eta_{plant} C_{soil} + I_s C_{soil} + I_W C_{water})TF \qquad (5.17)$$

where

I_s	(kg/d) is the intake rate of contaminated soil by the animal
I_p	(kg/d) is the intake rate of contaminated plants by the animal
η_{plant}	is the plant:soil concentration ratio
C_{soil}	C_{soil} (Bq/kg dry weight) is the radionuclide concentration in soil
I_W	(m^3/d) is the intake rate of contaminated water by the animal
C_{water}	(Bq/m^3) is the radionuclide concentration in water
TF	(d/kg) is the animal transfer factor for the radionuclide and animal product of interest.

The dose equations for the other three exposure pathways, external irradiation, ingestion of dust and inhalation of dust, are similar to those presented in Section E8.5.4 for the longer term exposures to excavated materials.

E8.5.8 Gross Erosion

The exposure pathways and effective dose equations for the gross erosion scenario are similar to those for the climate change scenario, presented in Section E8.5.7.

E8.5.9 Site Flooding

The exposure pathways and effective dose equations for the site flooding scenario are similar to those for the climate change scenario, presented in Section E8.5.7.

E8.5.10 Contaminated Waters

In the study, it was assumed that drinking waters might be abstracted from well drilled at or around the region of the proposed repository. The basic equation is:

$$H_{water} = V_W C_{water} H_2 \qquad (5.18)$$

where

H_{water}	(Sv/yr) is the annual effective dose from ingestion of a specific contaminated food product
V_W	(m^3/yr) is the rate of consumption of water, averaged over the year of interest
C_{water}	(Bq/m^3) is the average concentration of the radionuclide in the ingested waters
H_2	(Sv/Bq) is the committed effective dose per unit intake value for the radionuclide.

The concentration of radionuclides in water can be estimated by noting that the partitioning of radionuclides between the sorbed and solution phases is governed by the sorption characteristics of the host soils. It can then be shown that:

$$C_{\text{water}} = \frac{\rho D_F C_{\text{soil}}}{\phi + \rho K_D} \qquad (5.19)$$

where ρ (kg/m^3) is the density of the soil
ϕ (-) is the porosity of the soil
D_F (-) is a dilution factor that represents mixing with uncontaminated waters.

This expression can be used to estimate the concentration in porewater, provided that the concentration is below the solubility limit of the radionuclide. It is believed that this would be the case.

E8.5.11 Effects of Gas

The approach adopted for the gas assessment is presented in Section E8.8.

E8.6 Estimated Radiological Doses

In this section, the results of the dose and risk assessment are set out for the settler critical groups. The results are presented in a set of tables, as follows:

Table E8.17 Doses and risks to borehole drillers
Table E8.18 Doses and risks to bulk excavation workers
Table E8.19 Doses and risks to road builders
Table E8.20 Doses and risks to archaeologists
Table E8.21 Doses and risks to settler inhabitants exposed by excavated materials
Table E8.22 Doses and risks to nomadic inhabitants exposed by excavated materials
Table E8.23 Doses and risks to settler children following the rocket crash
Table E8.24 Doses and risks to nomadic children following the rocket crash
Table E8.25 Doses and risks to the recovery team following an aircraft crash
Table E8.26 Doses and risks to settler inhabitants in a wetter climate
Table E8.27 Doses and risks to nomadic inhabitants in a wetter climate
Table E8.28 Doses and risks to settler inhabitants following gross erosion
Table E8.29 Doses and risks to nomadic inhabitants following gross erosion
Table E8.30 Doses and risks to settler inhabitants following site flooding
Table E8.31 Doses and risks to nomadic inhabitants following site flooding
Table E8.32 Doses and risks arising from consumption of contaminated well water.

Each table presents the results as a function of exposure pathway (i.e., summed over all radionuclides), along with the maximum individual contribution to the dose from a particular pathway, and the radionuclide that makes that contribution. Total effective dose, conditional risk and annual individual risk are also presented. The results are illustrated graphically in Figures E8.5–E8.19.

The results for each scenario are discussed in the following sections. In each case, it is assumed that an institutional period of control of 200 years applies after the repository is closed. Note, however, that the times given in Tables E8.17 to E8.32 are after repository closure, NOT after the period of institutional control ceases.

All of the results presented in this section were evaluated using the assumption of homogeneous mixing of wastes through the total waste volume. The effects of individual sources are discussed in Section E8.7.

TABLE E8.17 Annual effective doses (Sv) and risks to borehole drillers as a function of exposure pathway

	Inhalation			Ingestion			External			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	1.98E-06	1.74E-06	Am-241	8.58E-08	3.79E-08	Am-241	1.33E-06	8.96E-07	Co-60	**3.40E-06**	1.78E-06	Am-241	2.04E-07	**2.04E-11**
1.00E+00	1.97E-06	1.74E-06	Am-241	8.79E-08	3.78E-08	Am-241	1.21E-06	7.85E-07	Co-60	**3.28E-06**	1.78E-06	Am-241	1.97E-07	**1.97E-11**
2.15E+00	1.97E-06	1.74E-06	Am-241	9.14E-08	3.77E-08	Am-241	1.09E-06	6.75E-07	Co-60	**3.16E-06**	1.78E-06	Am-241	1.90E-07	**1.90E-11**
4.65E+00	1.97E-06	1.73E-06	Am-241	9.88E-08	3.76E-08	Am-241	8.86E-07	4.86E-07	Co-60	**2.96E-06**	1.77E-06	Am-241	1.78E-07	**1.78E-11**
1.00E+01	1.97E-06	1.72E-06	Am-241	1.13E-07	3.72E-08	Am-241	6.02E-07	3.06E-07	Cs-137	**2.69E-06**	1.76E-06	Am-241	1.61E-07	**1.61E-11**
2.15E+01	1.96E-06	1.68E-06	Am-241	1.35E-07	3.68E-08	Po-210	3.43E-07	2.34E-07	Cs-137	**2.43E-06**	1.72E-06	Am-241	1.46E-07	**1.46E-11**
4.65E+01	1.90E-06	1.62E-06	Am-241	1.61E-07	5.79E-08	Po-210	1.89E-07	1.32E-07	Cs-137	**2.25E-06**	1.66E-06	Am-241	1.35E-07	**1.35E-11**
1.00E+02	1.77E-06	1.49E-06	Am-241	1.74E-07	7.13E-08	Po-210	9.26E-08	4.50E-08	Ra-226	**2.04E-06**	1.52E-06	Am-241	1.22E-07	**1.22E-11**
2.15E+02	1.51E-06	1.24E-06	Am-241	1.66E-07	7.12E-08	Po-210	5.46E-08	4.28E-08	Ra-226	**1.73E-06**	1.26E-06	Am-241	1.04E-07	**1.04E-11**
4.65E+02	1.10E-06	8.28E-07	Am-241	1.44E-07	6.40E-08	Po-210	4.70E-08	3.85E-08	Ra-226	**1.29E-06**	8.47E-07	Am-241	7.73E-08	**7.73E-12**
1.00E+03	6.02E-07	3.51E-07	Am-241	1.09E-07	5.07E-08	Po-210	3.84E-08	3.05E-08	Ra-226	**7.49E-07**	3.59E-07	Am-241	4.50E-08	**4.50E-12**
2.15E+03	2.80E-07	7.18E-08	U-238	6.72E-08	3.08E-08	Po-210	2.60E-08	1.85E-08	Ra-226	**3.73E-07**	7.71E-08	U-238	2.24E-08	**2.24E-12**
4.65E+03	2.04E-07	7.18E-08	U-238	2.97E-08	1.05E-08	Po-210	1.37E-08	6.31E-09	Ra-226	**2.48E-07**	7.71E-08	U-238	1.49E-08	**1.49E-12**
1.00E+04	2.09E-07	7.18E-08	U-238	1.33E-08	4.21E-09	U-238	8.12E-09	3.51E-09	Th-228	**2.30E-07**	7.71E-08	U-238	1.38E-08	**1.38E-12**
2.15E+04	2.47E-07	7.18E-08	U-238	1.33E-08	4.21E-09	U-238	7.86E-09	3.51E-09	Th-228	**2.68E-07**	7.71E-08	U-238	1.61E-08	**1.61E-12**
4.65E+04	3.19E-07	9.18E-08	Ac-227	1.86E-08	4.21E-09	U-238	9.15E-09	3.51E-09	Th-228	**3.47E-07**	9.40E-08	Ac-227	2.08E-08	**2.08E-12**
1.00E+05	4.46E-07	1.29E-07	Ac-227	3.46E-08	9.46E-09	Po-210	1.36E-08	5.77E-09	Ra-226	**4.94E-07**	1.32E-07	Ac-227	2.96E-08	**2.96E-12**
2.15E+05	6.84E-07	2.45E-07	Th-230	7.73E-08	3.02E-08	Po-210	2.64E-08	1.84E-08	Ra-226	**7.88E-07**	2.51E-07	Th-230	4.73E-08	**4.73E-12**
4.65E+05	1.08E-06	5.53E-07	Th-230	1.55E-07	6.88E-08	Po-210	5.01E-08	4.20E-08	Ra-226	**1.28E-06**	5.65E-07	Th-230	7.69E-08	**7.69E-12**
1.00E+06	1.41E-06	8.20E-07	Th-230	2.23E-07	1.02E-07	Po-210	7.07E-08	6.25E-08	Ra-226	**1.71E-06**	8.38E-07	Th-230	1.02E-07	**1.02E-11**
2.15E+06	1.51E-06	8.94E-07	Th-230	2.41E-07	1.12E-07	Po-210	7.64E-08	6.82E-08	Ra-226	**1.82E-06**	9.14E-07	Th-230	1.09E-07	**1.09E-11**
4.65E+06	1.51E-06	8.97E-07	Th-230	2.42E-07	1.12E-07	Po-210	7.65E-08	6.84E-08	Ra-226	**1.83E-06**	9.16E-07	Th-230	1.10E-07	**1.10E-11**
1.00E+07	1.50E-06	8.96E-07	Th-230	2.42E-07	1.12E-07	Po-210	7.65E-08	6.83E-08	Ra-226	**1.82E-06**	9.16E-07	Th-230	1.09E-07	**1.09E-11**
2.15E+07	1.50E-06	8.94E-07	Th-230	2.41E-07	1.12E-07	Po-210	7.63E-08	6.82E-08	Ra-226	**1.82E-06**	9.14E-07	Th-230	1.09E-07	**1.09E-11**
4.65E+07	1.49E-06	8.91E-07	Th-230	2.40E-07	1.11E-07	Po-210	7.60E-08	6.79E-08	Ra-226	**1.81E-06**	9.10E-07	Th-230	1.08E-07	**1.08E-11**
1.00E+08	1.47E-06	8.83E-07	Th-230	2.38E-07	1.10E-07	Po-210	7.54E-08	6.74E-08	Ra-226	**1.78E-06**	9.03E-07	Th-230	1.07E-07	**1.07E-11**

TABLE E8.18 Annual effective doses (Sv) and risks to bulk excavation workers as a function of exposure pathway

	Inhalation			Ingestion			External			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	3.95E-05	3.49E-05	Am-241	3.43E-07	1.51E-07	Am-241	1.18E-04	8.51E-05	Co-60	**1.57E-04**	8.52E-05	Co-60	9.44E-06	**9.44E-10**
1.00E+00	3.95E-05	3.48E-05	Am-241	3.52E-07	1.51E-07	Am-241	1.06E-04	7.46E-05	Co-60	**1.46E-04**	7.47E-05	Co-60	8.78E-06	**8.78E-10**
2.15E+00	3.95E-05	3.48E-05	Am-241	3.66E-07	1.51E-07	Am-241	9.52E-05	6.41E-05	Co-60	**1.35E-04**	6.42E-05	Co-60	8.10E-06	**8.10E-10**
4.65E+00	3.95E-05	3.46E-05	Am-241	3.95E-07	1.50E-07	Am-241	7.58E-05	4.62E-05	Co-60	**1.16E-04**	4.62E-05	Co-60	6.94E-06	**6.94E-10**
1.00E+01	3.94E-05	3.43E-05	Am-241	4.51E-07	1.49E-07	Am-241	4.95E-05	2.28E-05	Co-60	**8.94E-05**	3.45E-05	Am-241	5.36E-06	**5.36E-10**
2.15E+01	3.91E-05	3.37E-05	Am-241	5.42E-07	1.47E-07	Po-210	2.65E-05	1.70E-05	Cs-137	**6.61E-05**	3.39E-05	Am-241	3.97E-06	**3.97E-10**
4.65E+01	3.80E-05	3.24E-05	Am-241	6.45E-07	2.32E-07	Po-210	1.41E-05	9.55E-06	Cs-137	**5.28E-05**	3.26E-05	Am-241	3.17E-06	**3.17E-10**
1.00E+02	3.54E-05	2.97E-05	Am-241	6.96E-07	2.85E-07	Po-210	7.05E-06	4.03E-06	Ra-226	**4.31E-05**	2.99E-05	Am-241	2.59E-06	**2.59E-10**
2.15E+02	3.03E-05	2.47E-05	Am-241	6.62E-07	2.85E-07	Po-210	4.27E-06	3.83E-06	Ra-226	**3.52E-05**	2.48E-05	Am-241	2.11E-06	**2.11E-10**
4.65E+02	2.19E-05	1.66E-05	Am-241	5.75E-07	2.56E-07	Po-210	3.68E-06	3.44E-06	Ra-226	**2.62E-05**	1.67E-05	Am-241	1.57E-06	**1.57E-10**
1.00E+03	1.20E-05	7.02E-06	Am-241	4.38E-07	2.03E-07	Po-210	2.95E-06	2.73E-06	Ra-226	**1.54E-05**	7.06E-06	Am-241	9.25E-07	**9.25E-11**
2.15E+03	5.60E-06	1.44E-06	U-238	2.69E-07	1.23E-07	Po-210	1.87E-06	1.66E-06	Ra-226	**7.74E-06**	2.15E-06	Ra-226	4.64E-07	**4.64E-11**
4.65E+03	4.08E-06	1.44E-06	U-238	1.19E-07	4.20E-08	Po-210	7.81E-07	5.64E-07	Ra-226	**4.98E-06**	1.45E-06	U-238	2.99E-07	**2.99E-11**
1.00E+04	4.18E-06	1.44E-06	U-238	5.34E-08	1.68E-08	U-238	2.78E-07	2.04E-07	Ra-228	**4.51E-06**	1.45E-06	U-238	2.70E-07	**2.70E-11**
2.15E+04	4.93E-06	1.44E-06	U-238	5.34E-08	1.68E-08	U-238	2.46E-07	2.04E-07	Ra-228	**5.23E-06**	1.45E-06	U-238	3.14E-07	**3.14E-11**
4.65E+04	6.38E-06	1.84E-06	Ac-227	7.46E-08	1.68E-08	U-238	3.48E-07	2.04E-07	Ra-228	**6.80E-06**	1.84E-06	Ac-227	4.08E-07	**4.08E-11**
1.00E+05	8.92E-06	2.58E-06	Ac-227	1.38E-07	3.78E-08	Po-210	7.35E-07	5.16E-07	Ra-226	**9.79E-06**	2.59E-06	Ac-227	5.88E-07	**5.88E-11**
2.15E+05	1.37E-05	4.91E-06	Th-230	3.09E-07	1.21E-07	Po-210	1.87E-06	1.65E-06	Ra-226	**1.59E-05**	4.93E-06	Th-230	9.51E-07	**9.51E-11**
4.65E+05	2.15E-05	1.11E-05	Th-230	6.20E-07	2.75E-07	Po-210	3.97E-06	3.75E-06	Ra-226	**2.61E-05**	1.11E-05	Th-230	1.57E-06	**1.57E-10**
1.00E+06	2.83E-05	1.64E-05	Th-230	8.91E-07	4.10E-07	Po-210	5.81E-06	5.59E-06	Ra-226	**3.50E-05**	1.65E-05	Th-230	2.10E-06	**2.10E-10**
2.15E+06	3.01E-05	1.79E-05	Th-230	9.66E-07	4.47E-07	Po-210	6.31E-06	6.09E-06	Ra-226	**3.74E-05**	1.80E-05	Th-230	2.24E-06	**2.24E-10**
4.65E+06	3.01E-05	1.79E-05	Th-230	9.68E-07	4.48E-07	Po-210	6.33E-06	6.11E-06	Ra-226	**3.74E-05**	1.80E-05	Th-230	2.25E-06	**2.25E-10**
1.00E+07	3.01E-05	1.79E-05	Th-230	9.67E-07	4.48E-07	Po-210	6.33E-06	6.11E-06	Ra-226	**3.74E-05**	1.80E-05	Th-230	2.24E-06	**2.24E-10**
2.15E+07	3.00E-05	1.79E-05	Th-230	9.65E-07	4.47E-07	Po-210	6.32E-06	6.10E-06	Ra-226	**3.73E-05**	1.80E-05	Th-230	2.24E-06	**2.24E-10**
4.65E+07	2.98E-05	1.78E-05	Th-230	9.61E-07	4.45E-07	Po-210	6.29E-06	6.07E-06	Ra-226	**3.70E-05**	1.79E-05	Th-230	2.22E-06	**2.22E-10**
1.00E+08	2.94E-05	1.77E-05	Th-230	9.53E-07	4.42E-07	Po-210	6.24E-06	6.02E-06	Ra-226	**3.66E-05**	1.77E-05	Th-230	2.20E-06	**2.20E-10**

TABLE E8.19 Annual effective doses (Sv) and risks to road builders as a function of exposure pathway

	Inhalation			Ingestion			External			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	6.92E-05	6.10E-05	Am-241	3.00E-06	1.32E-06	Am-241	1.03E-03	7.45E-04	Co-60	**1.10E-03**	7.45E-04	Co-60	6.60E-05	**1.39E-09**
1.00E+00	6.91E-05	6.09E-05	Am-241	3.08E-06	1.32E-06	Am-241	9.31E-04	6.53E-04	Co-60	**1.00E-03**	6.53E-04	Co-60	6.02E-05	**1.26E-09**
2.15E+00	6.91E-05	6.08E-05	Am-241	3.20E-06	1.32E-06	Am-241	8.33E-04	5.61E-04	Co-60	**9.05E-04**	5.61E-04	Co-60	5.43E-05	**1.14E-09**
4.65E+00	6.91E-05	6.06E-05	Am-241	3.46E-06	1.31E-06	Am-241	6.63E-04	4.04E-04	Co-60	**7.36E-04**	4.04E-04	Co-60	4.41E-05	**9.27E-10**
1.00E+01	6.90E-05	6.01E-05	Am-241	3.95E-06	1.30E-06	Am-241	4.33E-04	2.00E-04	Co-60	**5.06E-04**	2.00E-04	Co-60	3.04E-05	**6.38E-10**
2.15E+01	6.84E-05	5.90E-05	Am-241	4.74E-06	1.29E-06	Po-210	2.32E-04	1.49E-04	Cs-137	**3.05E-04**	1.49E-04	Cs-137	1.83E-05	**3.84E-10**
4.65E+01	6.65E-05	5.67E-05	Am-241	5.65E-06	2.03E-06	Po-210	1.24E-04	8.35E-05	Cs-137	**1.96E-04**	8.38E-05	Cs-137	1.17E-05	**2.47E-10**
1.00E+02	6.19E-05	5.20E-05	Am-241	6.09E-06	2.50E-06	Po-210	6.17E-05	3.52E-05	Ra-226	**1.30E-04**	5.35E-05	Am-241	7.78E-06	**1.63E-10**
2.15E+02	5.30E-05	4.32E-05	Am-241	5.80E-06	2.49E-06	Po-210	3.74E-05	3.35E-05	Ra-226	**9.62E-05**	4.44E-05	Am-241	5.77E-06	**1.21E-10**
4.65E+02	3.84E-05	2.90E-05	Am-241	5.03E-06	2.24E-06	Po-210	3.22E-05	3.01E-05	Ra-226	**7.56E-05**	3.23E-05	Ra-226	4.54E-06	**9.52E-11**
1.00E+03	2.11E-05	1.23E-05	Am-241	3.83E-06	1.78E-06	Po-210	2.58E-05	2.39E-05	Ra-226	**5.07E-05**	2.56E-05	Ra-226	3.04E-06	**6.39E-11**
2.15E+03	9.80E-06	2.51E-06	U-238	2.35E-06	1.08E-06	Po-210	1.64E-05	1.45E-05	Ra-226	**2.85E-05**	1.55E-05	Ra-226	1.71E-06	**3.60E-11**
4.65E+03	7.15E-06	2.51E-06	U-238	1.04E-06	3.67E-07	Po-210	6.83E-06	4.94E-06	Ra-226	**1.50E-05**	5.30E-06	Ra-226	9.01E-07	**1.89E-11**
1.00E+04	7.31E-06	2.51E-06	U-238	4.67E-07	1.47E-07	U-238	2.43E-06	1.79E-06	Ra-228	**1.02E-05**	2.66E-06	U-238	6.13E-07	**1.29E-11**
2.15E+04	8.64E-06	2.51E-06	U-238	4.67E-07	1.47E-07	U-238	2.15E-06	1.79E-06	Ra-228	**1.13E-05**	2.66E-06	U-238	6.75E-07	**1.42E-11**
4.65E+04	1.12E-05	3.21E-06	Ac-227	6.53E-07	1.47E-07	U-238	3.04E-06	1.79E-06	Ra-228	**1.49E-05**	3.28E-06	Ac-227	8.92E-07	**1.87E-11**
1.00E+05	1.56E-05	4.52E-06	Ac-227	1.21E-06	3.31E-07	Po-210	6.43E-06	4.52E-06	Ra-226	**2.33E-05**	4.85E-06	Ra-226	1.40E-06	**2.93E-11**
2.15E+05	2.39E-05	8.59E-06	Th-230	2.71E-06	1.06E-06	Po-210	1.63E-05	1.44E-05	Ra-226	**4.30E-05**	1.55E-05	Ra-226	2.58E-06	**5.42E-11**
4.65E+05	3.77E-05	1.93E-05	Th-230	5.43E-06	2.41E-06	Po-210	3.48E-05	3.28E-05	Ra-226	**7.79E-05**	3.52E-05	Ra-226	4.67E-06	**9.81E-11**
1.00E+06	4.95E-05	2.87E-05	Th-230	7.80E-06	3.59E-06	Po-210	5.08E-05	4.89E-05	Ra-226	**1.08E-04**	5.25E-05	Ra-226	6.49E-06	**1.36E-10**
2.15E+06	5.27E-05	3.13E-05	Th-230	8.45E-06	3.91E-06	Po-210	5.53E-05	5.33E-05	Ra-226	**1.16E-04**	5.72E-05	Ra-226	6.98E-06	**1.47E-10**
4.65E+06	5.27E-05	3.14E-05	Th-230	8.47E-06	3.92E-06	Po-210	5.54E-05	5.35E-05	Ra-226	**1.17E-04**	5.74E-05	Ra-226	7.00E-06	**1.47E-10**
1.00E+07	5.26E-05	3.14E-05	Th-230	8.46E-06	3.92E-06	Po-210	5.54E-05	5.34E-05	Ra-226	**1.16E-04**	5.73E-05	Ra-226	6.99E-06	**1.47E-10**
2.15E+07	5.25E-05	3.13E-05	Th-230	8.45E-06	3.91E-06	Po-210	5.53E-05	5.33E-05	Ra-226	**1.16E-04**	5.72E-05	Ra-226	6.97E-06	**1.46E-10**
4.65E+07	5.21E-05	3.12E-05	Th-230	8.41E-06	3.90E-06	Po-210	5.51E-05	5.31E-05	Ra-226	**1.16E-04**	5.70E-05	Ra-226	6.94E-06	**1.46E-10**
1.00E+08	5.15E-05	3.09E-05	Th-230	8.33E-06	3.87E-06	Po-210	5.46E-05	5.27E-05	Ra-226	**1.14E-04**	5.65E-05	Ra-226	6.86E-06	**1.44E-10**

TABLE E8.20 Annual effective doses (Sv) and risks to archaeologists as a function of exposure pathway

	Inhalation			Ingestion			External			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	1.98E-03	1.74E-03	Am-241	1.72E-05	7.57E-06	Am-241	5.88E-03	4.26E-03	Co-60	**7.87E-03**	4.26E-03	Co-60	4.72E-04	**4.72E-08**
1.00E+00	1.97E-03	1.74E-03	Am-241	1.76E-05	7.56E-06	Am-241	5.32E-03	3.73E-03	Co-60	**7.31E-03**	3.73E-03	Co-60	4.39E-04	**4.39E-08**
2.15E+00	1.97E-03	1.74E-03	Am-241	1.83E-05	7.54E-06	Am-241	4.76E-03	3.21E-03	Co-60	**6.75E-03**	3.21E-03	Co-60	4.05E-04	**4.05E-08**
4.65E+00	1.97E-03	1.73E-03	Am-241	1.98E-05	7.51E-06	Am-241	3.79E-03	2.31E-03	Co-60	**5.78E-03**	2.31E-03	Co-60	3.47E-04	**3.47E-08**
1.00E+01	1.97E-03	1.72E-03	Am-241	2.26E-05	7.45E-06	Am-241	2.48E-03	1.14E-03	Co-60	**4.47E-03**	1.73E-03	Am-241	2.68E-04	**2.68E-08**
2.15E+01	1.96E-03	1.68E-03	Am-241	2.71E-05	7.35E-06	Po-210	1.32E-03	8.49E-04	Cs-137	**3.31E-03**	1.69E-03	Am-241	1.98E-04	**1.98E-08**
4.65E+01	1.90E-03	1.62E-03	Am-241	3.23E-05	1.16E-05	Po-210	7.06E-04	4.77E-04	Cs-137	**2.64E-03**	1.63E-03	Am-241	1.58E-04	**1.58E-08**
1.00E+02	1.77E-03	1.49E-03	Am-241	3.48E-05	1.43E-05	Po-210	3.53E-04	2.01E-04	Ra-226	**2.16E-03**	1.49E-03	Am-241	1.29E-04	**1.29E-08**
2.15E+02	1.51E-03	1.24E-03	Am-241	3.31E-05	1.42E-05	Po-210	2.14E-04	1.92E-04	Ra-226	**1.76E-03**	1.24E-03	Am-241	1.06E-04	**1.06E-08**
4.65E+02	1.10E-03	8.28E-04	Am-241	2.87E-05	1.28E-05	Po-210	1.84E-04	1.72E-04	Ra-226	**1.31E-03**	8.33E-04	Am-241	7.86E-05	**7.86E-09**
1.00E+03	6.02E-04	3.51E-04	Am-241	2.19E-05	1.01E-05	Po-210	1.48E-04	1.36E-04	Ra-226	**7.71E-04**	3.53E-04	Am-241	4.63E-05	**4.63E-09**
2.15E+03	2.80E-04	7.18E-05	U-238	1.34E-05	6.16E-06	Po-210	9.37E-05	8.28E-05	Ra-226	**3.87E-04**	1.07E-04	Ra-226	2.32E-05	**2.32E-09**
4.65E+03	2.04E-04	7.18E-05	U-238	5.93E-06	2.10E-06	Po-210	3.90E-05	2.82E-05	Ra-226	**2.49E-04**	7.26E-05	U-238	1.49E-05	**1.49E-09**
1.00E+04	2.09E-04	7.18E-05	U-238	2.67E-06	8.41E-07	U-238	1.39E-05	1.02E-05	Ra-228	**2.25E-04**	7.26E-05	U-238	1.35E-05	**1.35E-09**
2.15E+04	2.47E-04	7.18E-05	U-238	2.67E-06	8.41E-07	U-238	1.23E-05	1.02E-05	Ra-228	**2.62E-04**	7.26E-05	U-238	1.57E-05	**1.57E-09**
4.65E+04	3.19E-04	9.18E-05	Ac-227	3.73E-06	8.41E-07	U-238	1.74E-05	1.02E-05	Ra-228	**3.40E-04**	9.22E-05	Ac-227	2.04E-05	**2.04E-09**
1.00E+05	4.46E-04	1.29E-04	Ac-227	6.92E-06	1.89E-06	Po-210	3.68E-05	2.58E-05	Ra-226	**4.90E-04**	1.30E-04	Ac-227	2.94E-05	**2.94E-09**
2.15E+05	6.84E-04	2.45E-04	Th-230	1.55E-05	6.05E-06	Po-210	9.34E-05	8.24E-05	Ra-226	**7.93E-04**	2.46E-04	Th-230	4.76E-05	**4.76E-09**
4.65E+05	1.08E-03	5.53E-04	Th-230	3.10E-05	1.38E-05	Po-210	1.99E-04	1.88E-04	Ra-226	**1.31E-03**	5.55E-04	Th-230	7.84E-05	**7.84E-09**
1.00E+06	1.41E-03	8.20E-04	Th-230	4.46E-05	2.05E-05	Po-210	2.90E-04	2.79E-04	Ra-226	**1.75E-03**	8.24E-04	Th-230	1.05E-04	**1.05E-08**
2.15E+06	1.51E-03	8.94E-04	Th-230	4.83E-05	2.24E-05	Po-210	3.16E-04	3.05E-04	Ra-226	**1.87E-03**	8.98E-04	Th-230	1.12E-04	**1.12E-08**
4.65E+06	1.51E-03	8.97E-04	Th-230	4.84E-05	2.24E-05	Po-210	3.17E-04	3.06E-04	Ra-226	**1.87E-03**	9.01E-04	Th-230	1.12E-04	**1.12E-08**
1.00E+07	1.50E-03	8.96E-04	Th-230	4.84E-05	2.24E-05	Po-210	3.16E-04	3.05E-04	Ra-226	**1.87E-03**	9.00E-04	Th-230	1.12E-04	**1.12E-08**
2.15E+07	1.50E-03	8.94E-04	Th-230	4.83E-05	2.24E-05	Po-210	3.16E-04	3.05E-04	Ra-226	**1.86E-03**	8.98E-04	Th-230	1.12E-04	**1.12E-08**
4.65E+07	1.49E-03	8.91E-04	Th-230	4.81E-05	2.23E-05	Po-210	3.15E-04	3.04E-04	Ra-226	**1.85E-03**	8.95E-04	Th-230	1.11E-04	**1.11E-08**
1.00E+08	1.47E-03	8.83E-04	Th-230	4.76E-05	2.21E-05	Po-210	3.12E-04	3.01E-04	Ra-226	**1.83E-03**	8.87E-04	Th-230	1.10E-04	**1.10E-08**

TABLE E8.21 Annual effective dose (Sv) and risks to future settler inhabitants exposed by excavated materials as a function of exposure pathway

	Inhalation			Ingestion			External			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	2.29E-04	2.02E-04	Am-241	3.18E-05	1.41E-05	Am-241	3.41E-02	2.47E-02	Co-60	**3.43E-02**	2.47E-02	Co-60	2.06E-03	**2.06E-06**
1.00E+00	2.29E-04	2.02E-04	Am-241	3.26E-05	1.40E-05	Am-241	3.09E-02	2.16E-02	Co-60	**3.11E-02**	2.16E-02	Co-60	1.87E-03	**1.87E-06**
2.15E+00	2.29E-04	2.02E-04	Am-241	3.39E-05	1.40E-05	Am-241	2.76E-02	1.86E-02	Co-60	**2.79E-02**	1.86E-02	Co-60	1.67E-03	**1.67E-06**
4.65E+00	2.29E-04	2.01E-04	Am-241	3.67E-05	1.39E-05	Am-241	2.20E-02	1.34E-02	Co-60	**2.22E-02**	1.34E-02	Co-60	1.33E-03	**1.33E-06**
1.00E+01	2.29E-04	1.99E-04	Am-241	4.19E-05	1.38E-05	Am-241	1.44E-02	6.63E-03	Co-60	**1.46E-02**	6.63E-03	Co-60	8.78E-04	**8.78E-07**
2.15E+01	2.27E-04	1.95E-04	Am-241	5.03E-05	1.36E-05	Po-210	7.68E-03	4.92E-03	Cs-137	**7.95E-03**	4.93E-03	Cs-137	4.77E-04	**4.77E-07**
4.65E+01	2.20E-04	1.88E-04	Am-241	5.99E-05	2.15E-05	Po-210	4.10E-03	2.77E-03	Cs-137	**4.38E-03**	2.77E-03	Cs-137	2.63E-04	**2.63E-07**
1.00E+02	2.05E-04	1.72E-04	Am-241	6.46E-05	2.65E-05	Po-210	2.04E-03	1.17E-03	Ra-226	**2.31E-03**	1.18E-03	Ra-226	1.39E-04	**1.39E-07**
2.15E+02	1.76E-04	1.43E-04	Am-241	6.15E-05	2.64E-05	Po-210	1.24E-03	1.11E-03	Ra-226	**1.48E-03**	1.12E-03	Ra-226	8.85E-05	**8.85E-08**
4.65E+02	1.27E-04	9.61E-05	Am-241	5.33E-05	2.37E-05	Po-210	1.07E-03	9.97E-04	Ra-226	**1.25E-03**	1.01E-03	Ra-226	7.48E-05	**7.48E-08**
1.00E+03	6.98E-05	4.07E-05	Am-241	4.06E-05	1.88E-05	Po-210	8.56E-04	7.91E-04	Ra-226	**9.67E-04**	8.00E-04	Ra-226	5.80E-05	**5.80E-08**
2.15E+03	3.25E-05	8.33E-06	U-238	2.49E-05	1.14E-05	Po-210	5.43E-04	4.80E-04	Ra-226	**6.01E-04**	4.85E-04	Ra-226	3.60E-05	**3.60E-08**
4.65E+03	2.37E-05	8.33E-06	U-238	1.10E-05	3.90E-06	Po-210	2.26E-04	1.64E-04	Ra-226	**2.61E-04**	1.65E-04	Ra-226	1.57E-05	**1.57E-08**
1.00E+04	2.42E-05	8.33E-06	U-238	4.95E-06	1.56E-06	U-238	8.06E-05	5.92E-05	Ra-228	**1.10E-04**	6.17E-05	Ra-228	6.59E-06	**6.59E-09**
2.15E+04	2.86E-05	8.33E-06	U-238	4.95E-06	1.56E-06	U-238	7.13E-05	5.92E-05	Ra-228	**1.05E-04**	6.17E-05	Ra-228	6.29E-06	**6.29E-09**
4.65E+04	3.70E-05	1.07E-05	Ac-227	6.92E-06	1.56E-06	U-238	1.01E-04	5.92E-05	Ra-228	**1.45E-04**	6.17E-05	Ra-228	8.69E-06	**8.69E-09**
1.00E+05	5.17E-05	1.50E-05	Ac-227	1.28E-05	3.51E-06	Po-210	2.13E-04	1.50E-04	Ra-226	**2.78E-04**	1.51E-04	Ra-226	1.67E-05	**1.67E-08**
2.15E+05	7.93E-05	2.85E-05	Th-230	2.87E-05	1.12E-05	Po-210	5.42E-04	4.78E-04	Ra-226	**6.50E-04**	4.83E-04	Ra-226	3.90E-05	**3.90E-08**
4.65E+05	1.25E-04	6.41E-05	Th-230	5.76E-05	2.55E-05	Po-210	1.15E-03	1.09E-03	Ra-226	**1.33E-03**	1.10E-03	Ra-226	8.01E-05	**8.01E-08**
1.00E+06	1.64E-04	9.51E-05	Th-230	8.27E-05	3.80E-05	Po-210	1.68E-03	1.62E-03	Ra-226	**1.93E-03**	1.64E-03	Ra-226	1.16E-04	**1.16E-07**
2.15E+06	1.75E-04	1.04E-04	Th-230	8.96E-05	4.15E-05	Po-210	1.83E-03	1.77E-03	Ra-226	**2.10E-03**	1.79E-03	Ra-226	1.26E-04	**1.26E-07**
4.65E+06	1.75E-04	1.04E-04	Th-230	8.98E-05	4.16E-05	Po-210	1.84E-03	1.77E-03	Ra-226	**2.10E-03**	1.79E-03	Ra-226	1.26E-04	**1.26E-07**
1.00E+07	1.74E-04	1.04E-04	Th-230	8.98E-05	4.16E-05	Po-210	1.83E-03	1.77E-03	Ra-226	**2.10E-03**	1.79E-03	Ra-226	1.26E-04	**1.26E-07**
2.15E+07	1.74E-04	1.04E-04	Th-230	8.96E-05	4.15E-05	Po-210	1.83E-03	1.77E-03	Ra-226	**2.10E-03**	1.79E-03	Ra-226	1.26E-04	**1.26E-07**
4.65E+07	1.73E-04	1.03E-04	Th-230	8.92E-05	4.13E-05	Po-210	1.82E-03	1.76E-03	Ra-226	**2.09E-03**	1.78E-03	Ra-226	1.25E-04	**1.25E-07**
1.00E+08	1.71E-04	1.02E-04	Th-230	8.84E-05	4.10E-05	Po-210	1.81E-03	1.75E-03	Ra-226	**2.07E-03**	1.77E-03	Ra-226	1.24E-04	**1.24E-07**

TABLE E8.22 Annual effective doses (Sv) and risks to future nomadic inhabitants exposed by excavated materials as a function of exposure pathway

	Inhalation			Ingestion			External			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	5.31E-05	4.69E-05	Am-241	1.84E-04	8.14E-05	Am-241	7.90E-03	5.72E-03	Co-60	**8.14E-03**	5.73E-03	Co-60	4.88E-04	**4.88E-07**
1.00E+00	5.31E-05	4.68E-05	Am-241	1.89E-04	8.13E-05	Am-241	7.15E-03	5.02E-03	Co-60	**7.39E-03**	5.02E-03	Co-60	4.44E-04	**4.44E-07**
2.15E+00	5.31E-05	4.67E-05	Am-241	1.97E-04	8.11E-05	Am-241	6.40E-03	4.31E-03	Co-60	**6.65E-03**	4.31E-03	Co-60	3.99E-04	**3.99E-07**
4.65E+00	5.31E-05	4.65E-05	Am-241	2.12E-04	8.08E-05	Am-241	5.09E-03	3.11E-03	Co-60	**5.36E-03**	3.11E-03	Co-60	3.22E-04	**3.22E-07**
1.00E+01	5.30E-05	4.61E-05	Am-241	2.43E-04	8.01E-05	Am-241	3.33E-03	1.54E-03	Co-60	**3.62E-03**	1.54E-03	Co-60	2.17E-04	**2.17E-07**
2.15E+01	5.26E-05	4.53E-05	Am-241	2.91E-04	7.90E-05	Po-210	1.78E-03	1.14E-03	Cs-137	**2.12E-03**	1.17E-03	Cs-137	1.27E-04	**1.27E-07**
4.65E+01	5.10E-05	4.35E-05	Am-241	3.47E-04	1.24E-04	Po-210	9.49E-04	6.42E-04	Cs-137	**1.35E-03**	6.55E-04	Cs-137	8.09E-05	**8.09E-08**
1.00E+02	4.75E-05	3.99E-05	Am-241	3.74E-04	1.53E-04	Po-210	4.74E-04	2.71E-04	Ra-226	**8.96E-04**	3.09E-04	Ra-226	5.37E-05	**5.37E-08**
2.15E+02	4.07E-05	3.32E-05	Am-241	3.56E-04	1.53E-04	Po-210	2.87E-04	2.57E-04	Ra-226	**6.84E-04**	2.94E-04	Ra-226	4.10E-05	**4.10E-08**
4.65E+02	2.95E-05	2.23E-05	Am-241	3.09E-04	1.38E-04	Po-210	2.47E-04	2.31E-04	Ra-226	**5.85E-04**	2.64E-04	Ra-226	3.51E-05	**3.51E-08**
1.00E+03	1.62E-05	9.43E-06	Am-241	2.35E-04	1.09E-04	Po-210	1.98E-04	1.83E-04	Ra-226	**4.50E-04**	2.09E-04	Ra-226	2.70E-05	**2.70E-08**
2.15E+03	7.52E-06	1.93E-06	U-238	1.45E-04	6.62E-05	Po-210	1.26E-04	1.11E-04	Ra-226	**2.78E-04**	1.27E-04	Ra-226	1.67E-05	**1.67E-08**
4.65E+03	5.49E-06	1.93E-06	U-238	6.38E-05	2.26E-05	Po-210	5.25E-05	3.79E-05	Ra-226	**1.22E-04**	4.33E-05	Ra-226	7.30E-06	**7.30E-09**
1.00E+04	5.61E-06	1.93E-06	U-238	2.87E-05	9.04E-06	U-238	1.87E-05	1.37E-05	Ra-228	**5.30E-05**	2.26E-05	Ra-228	3.18E-06	**3.18E-09**
2.15E+04	6.63E-06	1.93E-06	U-238	2.87E-05	9.04E-06	U-238	1.65E-05	1.37E-05	Ra-228	**5.19E-05**	2.26E-05	Ra-228	3.11E-06	**3.11E-09**
4.65E+04	8.58E-06	2.47E-06	Ac-227	4.01E-05	9.04E-06	U-238	2.34E-05	1.37E-05	Ra-228	**7.20E-05**	2.26E-05	Ra-228	4.32E-06	**4.32E-09**
1.00E+05	1.20E-05	3.47E-06	Ac-227	7.44E-05	2.03E-05	Po-210	4.94E-05	3.47E-05	Ra-226	**1.36E-04**	3.96E-05	Ra-226	8.15E-06	**8.15E-09**
2.15E+05	1.84E-05	6.59E-06	Th-230	1.66E-04	6.50E-05	Po-210	1.26E-04	1.11E-04	Ra-226	**3.10E-04**	1.27E-04	Ra-226	1.86E-05	**1.86E-08**
4.65E+05	2.90E-05	1.49E-05	Th-230	3.34E-04	1.48E-04	Po-210	2.67E-04	2.52E-04	Ra-226	**6.29E-04**	2.88E-04	Ra-226	3.78E-05	**3.78E-08**
1.00E+06	3.80E-05	2.20E-05	Th-230	4.79E-04	2.20E-04	Po-210	3.90E-04	3.75E-04	Ra-226	**9.07E-04**	4.29E-04	Ra-226	5.44E-05	**5.44E-08**
2.15E+06	4.05E-05	2.40E-05	Th-230	5.19E-04	2.40E-04	Po-210	4.24E-04	4.09E-04	Ra-226	**9.84E-04**	4.68E-04	Ra-226	5.90E-05	**5.90E-08**
4.65E+06	4.05E-05	2.41E-05	Th-230	5.20E-04	2.41E-04	Po-210	4.26E-04	4.11E-04	Ra-226	**9.86E-04**	4.69E-04	Ra-226	5.92E-05	**5.92E-08**
1.00E+07	4.04E-05	2.41E-05	Th-230	5.20E-04	2.41E-04	Po-210	4.25E-04	4.10E-04	Ra-226	**9.86E-04**	4.69E-04	Ra-226	5.91E-05	**5.91E-08**
2.15E+07	4.03E-05	2.40E-05	Th-230	5.19E-04	2.40E-04	Po-210	4.24E-04	4.10E-04	Ra-226	**9.84E-04**	4.68E-04	Ra-226	5.90E-05	**5.90E-08**
4.65E+07	4.00E-05	2.39E-05	Th-230	5.17E-04	2.39E-04	Po-210	4.23E-04	4.08E-04	Ra-226	**9.80E-04**	4.66E-04	Ra-226	5.88E-05	**5.88E-08**
1.00E+08	3.95E-05	2.37E-05	Th-230	5.12E-04	2.37E-04	Po-210	4.19E-04	4.05E-04	Ra-226	**9.71E-04**	4.62E-04	Ra-226	5.83E-05	**5.83E-08**

TABLE E8.23 Annual effective doses (Sv) and risks arising after a rocket crash to settler children as a function of exposure pathway

	Inhalation			Ingestion			External			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	7.21E-04	6.37E-04	Am-241	1.00E-05	4.42E-06	Am-241	1.07E-02	7.77E-03	Co-60	**1.15E-02**	7.77E-03	Co-60	6.87E-04	2.06E-08
1.00E+00	7.21E-04	6.36E-04	Am-241	1.03E-05	4.41E-06	Am-241	9.71E-03	6.81E-03	Co-60	**1.04E-02**	6.81E-03	Co-60	6.26E-04	1.88E-08
2.15E+00	7.21E-04	6.34E-04	Am-241	1.07E-05	4.41E-06	Am-241	8.69E-03	5.85E-03	Co-60	**9.42E-03**	5.85E-03	Co-60	5.65E-04	1.70E-08
4.65E+00	7.21E-04	6.32E-04	Am-241	1.15E-05	4.39E-06	Am-241	6.92E-03	4.22E-03	Co-60	**7.65E-03**	4.22E-03	Co-60	4.59E-04	1.38E-08
1.00E+01	7.20E-04	6.26E-04	Am-241	1.32E-05	4.35E-06	Am-241	4.52E-03	2.08E-03	Co-60	**5.25E-03**	2.09E-03	Co-60	3.15E-04	9.45E-09
2.15E+01	7.14E-04	6.15E-04	Am-241	1.58E-05	4.29E-06	Po-210	2.42E-03	1.55E-03	Cs-137	**3.14E-03**	1.55E-03	Cs-137	1.89E-04	5.67E-09
4.65E+01	6.93E-04	5.91E-04	Am-241	1.88E-05	6.76E-06	Po-210	1.29E-03	8.71E-04	Cs-137	**2.00E-03**	8.73E-04	Cs-137	1.20E-04	3.60E-09
1.00E+02	6.46E-04	5.42E-04	Am-241	2.03E-05	8.33E-06	Po-210	6.43E-04	3.67E-04	Ra-226	**1.31E-03**	5.49E-04	Am-241	7.86E-05	2.36E-09
2.15E+02	5.53E-04	4.51E-04	Am-241	1.93E-05	8.31E-06	Po-210	3.90E-04	3.49E-04	Ra-226	**9.62E-04**	4.57E-04	Am-241	5.77E-05	1.73E-09
4.65E+02	4.00E-04	3.02E-04	Am-241	1.68E-05	7.47E-06	Po-210	3.35E-04	3.14E-04	Ra-226	**7.53E-04**	3.33E-04	Ra-226	4.52E-05	1.36E-09
1.00E+03	2.20E-04	1.28E-04	Am-241	1.28E-05	5.92E-06	Po-210	2.69E-04	2.49E-04	Ra-226	**5.02E-04**	2.64E-04	Ra-226	3.01E-05	9.03E-10
2.15E+03	1.02E-04	2.62E-05	U-238	7.85E-06	3.60E-06	Po-210	1.71E-04	1.51E-04	Ra-226	**2.81E-04**	1.60E-04	Ra-226	1.69E-05	5.07E-10
4.65E+03	7.45E-05	2.62E-05	U-238	3.47E-06	1.23E-06	Po-210	7.12E-05	5.15E-05	Ra-226	**1.49E-04**	5.46E-05	Ra-226	8.95E-06	2.69E-10
1.00E+04	7.62E-05	2.62E-05	U-238	1.56E-06	4.91E-07	U-238	2.54E-05	1.86E-05	Ra-228	**1.03E-04**	2.67E-05	U-238	6.19E-06	1.86E-10
2.15E+04	9.01E-05	2.62E-05	U-238	1.56E-06	4.91E-07	U-238	2.24E-05	1.86E-05	Ra-228	**1.14E-04**	2.67E-05	U-238	6.84E-06	2.05E-10
4.65E+04	1.16E-04	3.35E-05	Ac-227	2.18E-06	4.91E-07	U-238	3.17E-05	1.86E-05	Ra-228	**1.50E-04**	3.37E-05	Ac-227	9.02E-06	2.71E-10
1.00E+05	1.63E-04	4.71E-05	Ac-227	4.04E-06	1.11E-06	Po-210	6.71E-05	4.71E-05	Ra-226	**2.34E-04**	5.00E-05	Ra-226	1.40E-05	4.20E-10
2.15E+05	2.50E-04	8.95E-05	Th-230	9.03E-06	3.53E-06	Po-210	1.70E-04	1.50E-04	Ra-226	**4.29E-04**	1.60E-04	Ra-226	2.57E-05	7.71E-10
4.65E+05	3.93E-04	2.02E-04	Th-230	1.81E-05	8.03E-06	Po-210	3.62E-04	3.42E-04	Ra-226	**7.74E-04**	3.63E-04	Ra-226	4.64E-05	1.39E-09
1.00E+06	5.16E-04	2.99E-04	Th-230	2.60E-05	1.20E-05	Po-210	5.30E-04	5.10E-04	Ra-226	**1.07E-03**	5.41E-04	Ra-226	6.43E-05	1.93E-09
2.15E+06	5.50E-04	3.26E-04	Th-230	2.82E-05	1.31E-05	Po-210	5.76E-04	5.56E-04	Ra-226	**1.15E-03**	5.90E-04	Ra-226	6.92E-05	2.08E-09
4.65E+06	5.50E-04	3.27E-04	Th-230	2.83E-05	1.31E-05	Po-210	5.78E-04	5.58E-04	Ra-226	**1.16E-03**	5.92E-04	Ra-226	6.94E-05	2.08E-09
1.00E+07	5.49E-04	3.27E-04	Th-230	2.82E-05	1.31E-05	Po-210	5.77E-04	5.57E-04	Ra-226	**1.15E-03**	5.91E-04	Ra-226	6.93E-05	2.08E-09
2.15E+07	5.47E-04	3.26E-04	Th-230	2.82E-05	1.31E-05	Po-210	5.76E-04	5.56E-04	Ra-226	**1.15E-03**	5.90E-04	Ra-226	6.91E-05	2.07E-09
4.65E+07	5.44E-04	3.25E-04	Th-230	2.81E-05	1.30E-05	Po-210	5.74E-04	5.54E-04	Ra-226	**1.15E-03**	5.88E-04	Ra-226	6.88E-05	2.06E-09
1.00E+08	5.37E-04	3.22E-04	Th-230	2.78E-05	1.29E-05	Po-210	5.69E-04	5.49E-04	Ra-226	**1.13E-03**	5.83E-04	Ra-226	6.80E-05	2.04E-09

TABLE E8.24 Annual effective doses (Sv) and risks arising after a rocket crash to nomad children as a function of exposure pathway

	Inhalation			Ingestion			External			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	8.30E-05	7.33E-05	Am-241	2.88E-05	1.27E-05	Am-241	1.23E-03	8.94E-04	Co-60	**1.35E-03**	8.95E-04	Co-60	8.08E-05	2.42E-09
1.00E+00	8.29E-05	7.31E-05	Am-241	2.95E-05	1.27E-05	Am-241	1.12E-03	7.84E-04	Co-60	**1.23E-03**	7.85E-04	Co-60	7.38E-05	2.21E-09
2.15E+00	8.29E-05	7.30E-05	Am-241	3.07E-05	1.27E-05	Am-241	1.00E-03	6.73E-04	Co-60	**1.11E-03**	6.74E-04	Co-60	6.68E-05	2.00E-09
4.65E+00	8.29E-05	7.27E-05	Am-241	3.32E-05	1.26E-05	Am-241	7.96E-04	4.85E-04	Co-60	**9.12E-04**	4.86E-04	Co-60	5.47E-05	1.64E-09
1.00E+01	8.28E-05	7.21E-05	Am-241	3.79E-05	1.25E-05	Am-241	5.20E-04	2.40E-04	Co-60	**6.41E-04**	2.40E-04	Co-60	3.84E-05	1.15E-09
2.15E+01	8.21E-05	7.08E-05	Am-241	4.55E-05	1.23E-05	Po-210	2.78E-04	1.78E-04	Cs-137	**4.06E-04**	1.82E-04	Cs-137	2.43E-05	7.29E-10
4.65E+01	7.98E-05	6.80E-05	Am-241	5.42E-05	1.94E-05	Po-210	1.48E-04	1.00E-04	Cs-137	**2.82E-04**	1.02E-04	Cs-137	1.69E-05	5.07E-10
1.00E+02	7.43E-05	6.24E-05	Am-241	5.85E-05	2.40E-05	Po-210	7.40E-05	4.23E-05	Ra-226	**2.07E-04**	7.36E-05	Am-241	1.24E-05	3.72E-10
2.15E+02	6.36E-05	5.19E-05	Am-241	5.56E-05	2.39E-05	Po-210	4.48E-05	4.02E-05	Ra-226	**1.64E-04**	6.12E-05	Am-241	9.84E-06	2.95E-10
4.65E+02	4.61E-05	3.48E-05	Am-241	4.83E-05	2.15E-05	Po-210	3.86E-05	3.61E-05	Ra-226	**1.33E-04**	4.31E-05	Ra-226	7.98E-06	2.39E-10
1.00E+03	2.53E-05	1.47E-05	Am-241	3.68E-05	1.70E-05	Po-210	3.10E-05	2.86E-05	Ra-226	**9.30E-05**	3.41E-05	Ra-226	5.58E-06	1.67E-10
2.15E+03	1.18E-05	3.01E-06	U-238	2.26E-05	1.03E-05	Po-210	1.97E-05	1.74E-05	Ra-226	**5.40E-05**	2.07E-05	Ra-226	3.24E-06	9.72E-11
4.65E+03	8.58E-06	3.01E-06	U-238	9.97E-06	3.53E-06	Po-210	8.20E-06	5.92E-06	Ra-226	**2.67E-05**	7.07E-06	Ra-226	1.60E-06	4.80E-11
1.00E+04	8.77E-06	3.01E-06	U-238	4.48E-06	1.41E-06	U-238	2.92E-06	2.14E-06	Ra-228	**1.62E-05**	4.43E-06	U-238	9.70E-07	2.91E-11
2.15E+04	1.04E-05	3.01E-06	U-238	4.48E-06	1.41E-06	U-238	2.58E-06	2.14E-06	Ra-228	**1.74E-05**	4.43E-06	U-238	1.05E-06	3.15E-11
4.65E+04	1.34E-05	3.86E-06	Ac-227	6.27E-06	1.41E-06	U-238	3.65E-06	2.14E-06	Ra-228	**2.33E-05**	4.50E-06	Ac-227	1.40E-06	4.20E-11
1.00E+05	1.87E-05	5.42E-06	Ac-227	1.16E-05	3.18E-06	Po-210	7.72E-06	5.42E-06	Ra-226	**3.81E-05**	6.46E-06	Ra-226	2.28E-06	6.84E-11
2.15E+05	2.87E-05	1.03E-05	Th-230	2.60E-05	1.02E-05	Po-210	1.96E-05	1.73E-05	Ra-226	**7.43E-05**	2.06E-05	Ra-226	4.46E-06	1.34E-10
4.65E+05	4.52E-05	2.32E-05	Th-230	5.21E-05	2.31E-05	Po-210	4.17E-05	3.94E-05	Ra-226	**1.39E-04**	4.70E-05	Ra-226	8.34E-06	2.50E-10
1.00E+06	5.94E-05	3.44E-05	Th-230	7.49E-05	3.44E-05	Po-210	6.10E-05	5.87E-05	Ra-226	**1.95E-04**	7.00E-05	Ra-226	1.17E-05	3.51E-10
2.15E+06	6.32E-05	3.75E-05	Th-230	8.11E-05	3.75E-05	Po-210	6.63E-05	6.40E-05	Ra-226	**2.11E-04**	7.63E-05	Ra-226	1.26E-05	3.78E-10
4.65E+06	6.33E-05	3.77E-05	Th-230	8.13E-05	3.77E-05	Po-210	6.65E-05	6.42E-05	Ra-226	**2.11E-04**	7.65E-05	Ra-226	1.27E-05	3.81E-10
1.00E+07	6.32E-05	3.76E-05	Th-230	8.12E-05	3.76E-05	Po-210	6.64E-05	6.41E-05	Ra-226	**2.11E-04**	7.65E-05	Ra-226	1.26E-05	3.78E-10
2.15E+07	6.30E-05	3.76E-05	Th-230	8.11E-05	3.76E-05	Po-210	6.63E-05	6.40E-05	Ra-226	**2.10E-04**	7.63E-05	Ra-226	1.26E-05	3.78E-10
4.65E+07	6.26E-05	3.74E-05	Th-230	8.07E-05	3.74E-05	Po-210	6.61E-05	6.38E-05	Ra-226	**2.09E-04**	7.60E-05	Ra-226	1.26E-05	3.78E-10
1.00E+08	6.18E-05	3.71E-05	Th-230	8.00E-05	3.71E-05	Po-210	6.55E-05	6.32E-05	Ra-226	**2.07E-04**	7.54E-05	Ra-226	1.24E-05	3.72E-10

TABLE E8.25 Annual effective doses (Sv) and risks arising after an aircraft crash to the recovery team as a function of exposure pathway

	Inhalation			Ingestion			External			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	4.94E-05	4.36E-05	Am-241	2.14E-06	9.46E-07	Am-241	7.35E-04	5.32E-04	Co-60	**7.86E-04**	5.32E-04	Co-60	4.72E-05	**3.30E-12**
1.00E+00	4.94E-05	4.35E-05	Am-241	2.20E-06	9.45E-07	Am-241	6.65E-04	4.66E-04	Co-60	**7.17E-04**	4.67E-04	Co-60	4.30E-05	**3.01E-12**
2.15E+00	4.94E-05	4.35E-05	Am-241	2.28E-06	9.43E-07	Am-241	5.95E-04	4.01E-04	Co-60	**6.47E-04**	4.01E-04	Co-60	3.88E-05	**2.72E-12**
4.65E+00	4.94E-05	4.33E-05	Am-241	2.47E-06	9.39E-07	Am-241	4.74E-04	2.89E-04	Co-60	**5.26E-04**	2.89E-04	Co-60	3.15E-05	**2.21E-12**
1.00E+01	4.93E-05	4.29E-05	Am-241	2.82E-06	9.31E-07	Am-241	3.09E-04	1.43E-04	Co-60	**3.62E-04**	1.43E-04	Co-60	2.17E-05	**1.52E-12**
2.15E+01	4.89E-05	4.21E-05	Am-241	3.38E-06	9.19E-07	Po-210	1.65E-04	1.06E-04	Cs-137	**2.18E-04**	1.06E-04	Cs-137	1.31E-05	**9.17E-13**
4.65E+01	4.75E-05	4.05E-05	Am-241	4.03E-06	1.45E-06	Po-210	8.83E-05	5.97E-05	Cs-137	**1.40E-04**	5.99E-05	Cs-137	8.39E-06	**5.87E-13**
1.00E+02	4.42E-05	3.71E-05	Am-241	4.35E-06	1.78E-06	Po-210	4.41E-05	2.52E-05	Ra-226	**9.26E-05**	3.82E-05	Am-241	5.56E-06	**3.89E-13**
2.15E+02	3.78E-05	3.09E-05	Am-241	4.14E-06	1.78E-06	Po-210	2.67E-05	2.39E-05	Ra-226	**6.87E-05**	3.17E-05	Am-241	4.12E-06	**2.88E-13**
4.65E+02	2.74E-05	2.07E-05	Am-241	3.59E-06	1.60E-06	Po-210	2.30E-05	2.15E-05	Ra-226	**5.40E-05**	2.31E-05	Ra-226	3.24E-06	**2.27E-13**
1.00E+03	1.50E-05	8.77E-06	Am-241	2.74E-06	1.27E-06	Po-210	1.85E-05	1.70E-05	Ra-226	**3.62E-05**	1.83E-05	Ra-226	2.17E-06	**1.52E-13**
2.15E+03	7.00E-06	1.79E-06	U-238	1.68E-06	7.70E-07	Po-210	1.17E-05	1.03E-05	Ra-226	**2.04E-05**	1.11E-05	Ra-226	1.22E-06	**8.54E-14**
4.65E+03	5.10E-06	1.79E-06	U-238	7.42E-07	2.62E-07	Po-210	4.88E-06	3.53E-06	Ra-226	**1.07E-05**	3.78E-06	Ra-226	6.43E-07	**4.50E-14**
1.00E+04	5.22E-06	1.79E-06	U-238	3.34E-07	1.05E-07	U-238	1.74E-06	1.28E-06	Ra-228	**7.29E-06**	1.90E-06	U-238	4.38E-07	**3.07E-14**
2.15E+04	6.17E-06	1.79E-06	U-238	3.34E-07	1.05E-07	U-238	1.54E-06	1.28E-06	Ra-228	**8.04E-06**	1.90E-06	U-238	4.82E-07	**3.37E-14**
4.65E+04	7.98E-06	2.30E-06	Ac-227	4.66E-07	1.05E-07	U-238	2.17E-06	1.28E-06	Ra-228	**1.06E-05**	2.34E-06	Ac-227	6.37E-07	**4.46E-14**
1.00E+05	1.11E-05	3.23E-06	Ac-227	8.65E-07	2.37E-07	Po-210	4.59E-06	3.23E-06	Ra-226	**1.66E-05**	3.46E-06	Ra-226	9.96E-07	**6.97E-14**
2.15E+05	1.71E-05	6.13E-06	Th-230	1.93E-06	7.56E-07	Po-210	1.17E-05	1.03E-05	Ra-226	**3.07E-05**	1.11E-05	Ra-226	1.84E-06	**1.29E-13**
4.65E+05	2.69E-05	1.38E-05	Th-230	3.88E-06	1.72E-06	Po-210	2.48E-05	2.34E-05	Ra-226	**5.56E-05**	2.52E-05	Ra-226	3.34E-06	**2.34E-13**
1.00E+06	3.54E-05	2.05E-05	Th-230	5.57E-06	2.56E-06	Po-210	3.63E-05	3.49E-05	Ra-226	**7.72E-05**	3.75E-05	Ra-226	4.63E-06	**3.24E-13**
2.15E+06	3.76E-05	2.24E-05	Th-230	6.04E-06	2.79E-06	Po-210	3.95E-05	3.81E-05	Ra-226	**8.31E-05**	4.09E-05	Ra-226	4.99E-06	**3.49E-13**
4.65E+06	3.77E-05	2.24E-05	Th-230	6.05E-06	2.80E-06	Po-210	3.96E-05	3.82E-05	Ra-226	**8.33E-05**	4.10E-05	Ra-226	5.00E-06	**3.50E-13**
1.00E+07	3.76E-05	2.24E-05	Th-230	6.04E-06	2.80E-06	Po-210	3.95E-05	3.82E-05	Ra-226	**8.32E-05**	4.09E-05	Ra-226	4.99E-06	**3.49E-13**
2.15E+07	3.75E-05	2.24E-05	Th-230	6.03E-06	2.79E-06	Po-210	3.95E-05	3.81E-05	Ra-226	**8.30E-05**	4.09E-05	Ra-226	4.98E-06	**3.49E-13**
4.65E+07	3.72E-05	2.23E-05	Th-230	6.01E-06	2.78E-06	Po-210	3.93E-05	3.79E-05	Ra-226	**8.26E-05**	4.07E-05	Ra-226	4.95E-06	**3.47E-13**
1.00E+08	3.68E-05	2.21E-05	Th-230	5.95E-06	2.76E-06	Po-210	3.90E-05	3.76E-05	Ra-226	**8.17E-05**	4.04E-05	Ra-226	4.90E-06	**3.43E-13**

TABLE E8.26 Annual effective doses (Sv) and risks to settler inhabitants in a wetter climate as a function of exposure pathway

	Inhalation			Ingestion of plants			Ingestion of meat			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	5.73E-05	5.06E-05	Am-241	3.76E-04	1.56E-04	H-3	4.84E-04	3.14E-04	Cs-137	**1.77E-03**	6.28E-04	Co-60	1.06E-04	**1.06E-04**
1.00E+00	5.73E-05	5.05E-05	Am-241	3.63E-04	1.48E-04	H-3	4.70E-04	3.07E-04	Cs-137	**1.66E-03**	5.95E-04	Cs-137	9.99E-05	**9.99E-05**
2.15E+00	5.72E-05	5.04E-05	Am-241	3.49E-04	1.39E-04	H-3	4.57E-04	2.99E-04	Cs-137	**1.56E-03**	5.79E-04	Cs-137	9.34E-05	**9.34E-05**
4.65E+00	5.72E-05	5.02E-05	Am-241	3.23E-04	1.21E-04	H-3	4.30E-04	2.82E-04	Cs-137	**1.36E-03**	5.47E-04	Cs-137	8.18E-05	**8.18E-05**
1.00E+01	5.72E-05	4.98E-05	Am-241	2.75E-04	8.93E-05	H-3	3.82E-04	2.49E-04	Cs-137	**1.08E-03**	4.83E-04	Cs-137	6.46E-05	**6.46E-05**
2.15E+01	5.67E-05	4.89E-05	Am-241	2.04E-04	5.56E-05	Cs-137	3.06E-04	1.91E-04	Cs-137	**7.62E-04**	3.70E-04	Cs-137	4.57E-05	**4.57E-05**
4.65E+01	5.51E-05	4.69E-05	Am-241	1.28E-04	3.12E-05	Cs-137	2.15E-04	1.07E-04	Cs-137	**5.05E-04**	2.08E-04	Cs-137	3.03E-05	**3.03E-05**
1.00E+02	5.13E-05	4.31E-05	Am-241	7.84E-05	2.79E-05	Ra-226	1.43E-04	9.27E-05	Po-210	**3.29E-04**	1.07E-04	Po-210	1.97E-05	**1.97E-05**
2.15E+02	4.39E-05	3.58E-05	Am-241	6.06E-05	2.66E-05	Ra-226	1.11E-04	9.25E-05	Po-210	**2.51E-04**	1.07E-04	Po-210	1.51E-05	**1.51E-05**
4.65E+02	3.18E-05	2.40E-05	Am-241	5.44E-05	2.38E-05	Ra-226	9.76E-05	8.31E-05	Po-210	**2.15E-04**	9.60E-05	Po-210	1.29E-05	**1.29E-05**
1.00E+03	1.74E-05	1.02E-05	Am-241	4.51E-05	1.89E-05	Ra-226	7.75E-05	6.59E-05	Po-210	**1.65E-04**	7.61E-05	Po-210	9.88E-06	**9.88E-06**
2.15E+03	8.12E-06	2.08E-06	U-238	3.14E-05	1.15E-05	Ra-226	4.72E-05	4.00E-05	Po-210	**1.02E-04**	4.62E-05	Po-210	6.13E-06	**6.13E-06**
4.65E+03	5.92E-06	2.08E-06	U-238	1.74E-05	6.54E-06	Ra-228	1.63E-05	1.36E-05	Po-210	**4.61E-05**	1.58E-05	Po-210	2.77E-06	**2.77E-06**
1.00E+04	6.06E-06	2.08E-06	U-238	1.10E-05	6.54E-06	Ra-228	2.07E-06	1.49E-06	Po-210	**2.15E-05**	8.49E-06	Ra-228	1.29E-06	**1.29E-06**
2.15E+04	7.16E-06	2.08E-06	U-238	1.07E-05	6.54E-06	Ra-228	1.16E-06	6.87E-07	Po-210	**2.12E-05**	8.49E-06	Ra-228	1.27E-06	**1.27E-06**
4.65E+04	9.25E-06	2.66E-06	Ac-227	1.22E-05	6.54E-06	Ra-228	4.01E-06	3.09E-06	Po-210	**2.86E-05**	8.49E-06	Ra-228	1.71E-06	**1.71E-06**
1.00E+05	1.29E-05	3.74E-06	Ac-227	1.76E-05	6.54E-06	Ra-228	1.48E-05	1.23E-05	Po-210	**5.17E-05**	1.42E-05	Po-210	3.10E-06	**3.10E-06**
2.15E+05	1.98E-05	7.11E-06	Th-230	3.29E-05	1.14E-05	Ra-226	4.65E-05	3.93E-05	Po-210	**1.15E-04**	4.54E-05	Po-210	6.90E-06	**6.90E-06**
4.65E+05	3.12E-05	1.60E-05	Th-230	6.07E-05	2.60E-05	Ra-226	1.05E-04	8.94E-05	Po-210	**2.30E-04**	1.03E-04	Po-210	1.38E-05	**1.38E-05**
1.00E+06	4.10E-05	2.38E-05	Th-230	8.49E-05	3.88E-05	Ra-226	1.56E-04	1.33E-04	Po-210	**3.31E-04**	1.54E-04	Po-210	1.99E-05	**1.99E-05**
2.15E+06	4.37E-05	2.59E-05	Th-230	9.16E-05	4.23E-05	Ra-226	1.71E-04	1.45E-04	Po-210	**3.59E-04**	1.68E-04	Po-210	2.15E-05	**2.15E-05**
4.65E+06	4.37E-05	2.60E-05	Th-230	9.18E-05	4.24E-05	Ra-226	1.71E-04	1.46E-04	Po-210	**3.60E-04**	1.68E-04	Po-210	2.16E-05	**2.16E-05**
1.00E+07	4.36E-05	2.60E-05	Th-230	9.18E-05	4.24E-05	Ra-226	1.71E-04	1.46E-04	Po-210	**3.59E-04**	1.68E-04	Po-210	2.16E-05	**2.16E-05**
2.15E+07	4.35E-05	2.59E-05	Th-230	9.16E-05	4.23E-05	Ra-226	1.71E-04	1.45E-04	Po-210	**3.59E-04**	1.68E-04	Po-210	2.15E-05	**2.15E-05**
4.65E+07	4.32E-05	2.58E-05	Th-230	9.13E-05	4.21E-05	Ra-226	1.70E-04	1.45E-04	Po-210	**3.57E-04**	1.67E-04	Po-210	2.14E-05	**2.14E-05**
1.00E+08	4.26E-05	2.56E-05	Th-230	9.05E-05	4.18E-05	Ra-226	1.69E-04	1.44E-04	Po-210	**3.54E-04**	1.66E-04	Po-210	2.12E-05	**2.12E-05**

TABLE E8.27 Annual effective doses (Sv) and risks to nomadic inhabitants in a wetter climate as a function of exposure pathway

	Inhalation			Ingestion of plants			Ingestion of meat			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	1.33E-05	1.17E-05	Am-241	7.20E-05	2.82E-05	H-3	1.67E-04	8.43E-05	Cs-137	**4.57E-04**	1.53E-04	Cs-137	2.74E-05	**2.74E-05**
1.00E+00	1.33E-05	1.17E-05	Am-241	6.94E-05	2.66E-05	H-3	1.62E-04	8.23E-05	Cs-137	**4.31E-04**	1.50E-04	Cs-137	2.58E-05	**2.58E-05**
2.15E+00	1.33E-05	1.17E-05	Am-241	6.66E-05	2.50E-05	H-3	1.56E-04	8.02E-05	Cs-137	**4.03E-04**	1.46E-04	Cs-137	2.42E-05	**2.42E-05**
4.65E+00	1.33E-05	1.16E-05	Am-241	6.10E-05	2.17E-05	H-3	1.45E-04	7.57E-05	Cs-137	**3.55E-04**	1.38E-04	Cs-137	2.13E-05	**2.13E-05**
1.00E+01	1.33E-05	1.15E-05	Am-241	5.11E-05	1.64E-05	Cs-137	1.25E-04	6.69E-05	Cs-137	**2.82E-04**	1.22E-04	Cs-137	1.69E-05	**1.69E-05**
2.15E+01	1.31E-05	1.13E-05	Am-241	3.60E-05	1.26E-05	Cs-137	9.58E-05	5.12E-05	Cs-137	**2.01E-04**	9.33E-05	Cs-137	1.21E-05	**1.21E-05**
4.65E+01	1.28E-05	1.09E-05	Am-241	1.93E-05	7.08E-06	Cs-137	6.56E-05	2.88E-05	Cs-137	**1.35E-04**	5.25E-05	Cs-137	8.12E-06	**8.12E-06**
1.00E+02	1.19E-05	9.98E-06	Am-241	7.86E-06	2.05E-06	Cs-137	4.59E-05	3.31E-05	Po-210	**9.24E-05**	4.01E-05	Po-210	5.55E-06	**5.55E-06**
2.15E+02	1.02E-05	8.30E-06	Am-241	4.07E-06	1.70E-06	Ra-226	3.74E-05	3.30E-05	Po-210	**7.31E-05**	4.00E-05	Po-210	4.39E-06	**4.39E-06**
4.65E+02	7.37E-06	5.57E-06	Am-241	3.48E-06	1.53E-06	Ra-226	3.31E-05	2.97E-05	Po-210	**6.25E-05**	3.60E-05	Po-210	3.75E-06	**3.75E-06**
1.00E+03	4.04E-06	2.36E-06	Am-241	2.89E-06	1.21E-06	Ra-226	2.63E-05	2.35E-05	Po-210	**4.76E-05**	2.85E-05	Po-210	2.86E-06	**2.86E-06**
2.15E+03	1.88E-06	4.82E-07	U-238	2.01E-06	7.35E-07	Ra-226	1.60E-05	1.43E-05	Po-210	**2.88E-05**	1.73E-05	Po-210	1.73E-06	**1.73E-06**
4.65E+03	1.37E-06	4.82E-07	U-238	1.11E-06	4.18E-07	Ra-228	5.49E-06	4.87E-06	Po-210	**1.18E-05**	5.90E-06	Po-210	7.11E-07	**7.11E-07**
1.00E+04	1.40E-06	4.82E-07	U-238	7.06E-07	4.18E-07	Ra-228	6.65E-07	5.30E-07	Po-210	**4.39E-06**	1.20E-06	Ra-228	2.63E-07	**2.63E-07**
2.15E+04	1.66E-06	4.82E-07	U-238	6.87E-07	4.18E-07	Ra-228	3.50E-07	2.45E-07	Po-210	**4.26E-06**	1.20E-06	Ra-228	2.55E-07	**2.55E-07**
4.65E+04	2.14E-06	6.17E-07	Ac-227	7.86E-07	4.18E-07	Ra-228	1.31E-06	1.10E-06	Po-210	**6.43E-06**	1.34E-06	Po-210	3.86E-07	**3.86E-07**
1.00E+05	3.00E-06	8.67E-07	Ac-227	1.13E-06	4.18E-07	Ra-228	4.98E-06	4.39E-06	Po-210	**1.33E-05**	5.32E-06	Po-210	7.99E-07	**7.99E-07**
2.15E+05	4.60E-06	1.65E-06	Th-230	2.11E-06	7.31E-07	Ra-226	1.57E-05	1.40E-05	Po-210	**3.22E-05**	1.70E-05	Po-210	1.93E-06	**1.93E-06**
4.65E+05	7.24E-06	3.71E-06	Th-230	3.90E-06	1.66E-06	Ra-226	3.57E-05	3.19E-05	Po-210	**6.68E-05**	3.87E-05	Po-210	4.01E-06	**4.01E-06**
1.00E+06	9.50E-06	5.51E-06	Th-230	5.45E-06	2.48E-06	Ra-226	5.31E-05	4.75E-05	Po-210	**9.69E-05**	5.76E-05	Po-210	5.82E-06	**5.82E-06**
2.15E+06	1.01E-05	6.01E-06	Th-230	5.88E-06	2.70E-06	Ra-226	5.79E-05	5.18E-05	Po-210	**1.05E-04**	6.29E-05	Po-210	6.31E-06	**6.31E-06**
4.65E+06	1.01E-05	6.03E-06	Th-230	5.89E-06	2.71E-06	Ra-226	5.80E-05	5.20E-05	Po-210	**1.06E-04**	6.30E-05	Po-210	6.33E-06	**6.33E-06**
1.00E+07	1.01E-05	6.02E-06	Th-230	5.89E-06	2.71E-06	Ra-226	5.80E-05	5.19E-05	Po-210	**1.05E-04**	6.30E-05	Po-210	6.32E-06	**6.32E-06**
2.15E+07	1.01E-05	6.01E-06	Th-230	5.88E-06	2.70E-06	Ra-226	5.79E-05	5.19E-05	Po-210	**1.05E-04**	6.29E-05	Po-210	6.31E-06	**6.31E-06**
4.65E+07	1.00E-05	5.99E-06	Th-230	5.86E-06	2.69E-06	Ra-226	5.77E-05	5.17E-05	Po-210	**1.05E-04**	6.26E-05	Po-210	6.29E-06	**6.29E-06**
1.00E+08	9.88E-06	5.94E-06	Th-230	5.81E-06	2.67E-06	Ra-226	5.72E-05	5.12E-05	Po-210	**1.04E-04**	6.21E-05	Po-210	6.23E-06	**6.23E-06**

TABLE E8.28 Annual effective doses (Sv) and risks to settler inhabitants following gross erosion as a function of exposure pathway

	Inhalation			Ingestion of plants			Ingestion of meat			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	5.73E-06	5.06E-06	Am-241	3.76E-05	1.56E-05	H-3	4.84E-05	3.14E-05	Cs-137	**2.26E-04**	6.30E-05	Co-60	1.36E-05	**1.36E-05**
1.00E+00	5.73E-06	5.05E-06	Am-241	3.63E-05	1.48E-05	H-3	4.70E-05	3.07E-05	Cs-137	**2.15E-04**	5.98E-05	Cs-137	1.29E-05	**1.29E-05**
2.15E+00	5.72E-06	5.04E-06	Am-241	3.49E-05	1.39E-05	H-3	4.57E-05	2.99E-05	Cs-137	**2.04E-04**	5.82E-05	Cs-137	1.22E-05	**1.22E-05**
4.65E+00	5.72E-06	5.02E-06	Am-241	3.23E-05	1.21E-05	H-3	4.30E-05	2.82E-05	Cs-137	**1.84E-04**	5.50E-05	Cs-137	1.10E-05	**1.10E-05**
1.00E+01	5.72E-06	4.98E-06	Am-241	2.75E-05	8.93E-06	H-3	3.82E-05	2.49E-05	Cs-137	**1.55E-04**	4.86E-05	Cs-137	9.29E-06	**9.29E-06**
2.15E+01	5.67E-06	4.89E-06	Am-241	2.04E-05	5.56E-06	Cs-137	3.06E-05	1.91E-05	Cs-137	**1.23E-04**	3.72E-05	Cs-137	7.37E-06	**7.37E-06**
4.65E+01	5.51E-06	4.69E-06	Am-241	1.28E-05	3.12E-06	Cs-137	2.15E-05	1.07E-05	Cs-137	**9.72E-05**	2.82E-05	U-238	5.83E-06	**5.83E-06**
1.00E+02	5.13E-06	4.31E-06	Am-241	7.84E-06	2.79E-06	Ra-226	1.43E-05	9.27E-06	Po-210	**7.94E-05**	2.82E-05	U-238	4.76E-06	**4.76E-06**
2.15E+02	4.39E-06	3.58E-06	Am-241	6.06E-06	2.66E-06	Ra-226	1.11E-05	9.25E-06	Po-210	**7.04E-05**	2.82E-05	U-238	4.22E-06	**4.22E-06**
4.65E+02	3.18E-06	2.40E-06	Am-241	5.44E-06	2.38E-06	Ra-226	9.76E-06	8.31E-06	Po-210	**6.45E-05**	2.82E-05	U-238	3.87E-06	**3.87E-06**
1.00E+03	1.74E-06	1.02E-06	Am-241	4.51E-06	1.89E-06	Ra-226	7.75E-06	6.59E-06	Po-210	**5.60E-05**	2.82E-05	U-238	3.36E-06	**3.36E-06**
2.15E+03	8.12E-07	2.08E-07	U-238	3.14E-06	1.15E-06	Ra-226	4.72E-06	4.00E-06	Po-210	**4.53E-05**	2.82E-05	U-238	2.72E-06	**2.72E-06**
4.65E+03	5.92E-07	2.08E-07	U-238	1.74E-06	6.54E-07	Ra-228	1.63E-06	1.36E-06	Po-210	**3.57E-05**	2.82E-05	U-238	2.14E-06	**2.14E-06**
1.00E+04	6.06E-07	2.08E-07	U-238	1.10E-06	6.54E-07	Ra-228	2.07E-07	1.49E-07	Po-210	**3.18E-05**	2.82E-05	U-238	1.91E-06	**1.91E-06**
2.15E+04	7.16E-07	2.08E-07	U-238	1.07E-06	6.54E-07	Ra-228	1.16E-07	6.87E-08	Po-210	**3.27E-05**	2.82E-05	U-238	1.96E-06	**1.96E-06**
4.65E+04	9.25E-07	2.66E-07	Ac-227	1.22E-06	6.54E-07	Ra-228	4.01E-07	3.09E-07	Po-210	**3.58E-05**	2.82E-05	U-238	2.15E-06	**2.15E-06**
1.00E+05	1.29E-06	3.74E-07	Ac-227	1.76E-06	6.54E-07	Ra-228	1.48E-06	1.23E-06	Po-210	**4.34E-05**	2.82E-05	U-238	2.60E-06	**2.60E-06**
2.15E+05	1.98E-06	7.11E-07	Th-230	3.29E-06	1.14E-06	Ra-226	4.65E-06	3.93E-06	Po-210	**6.03E-05**	2.82E-05	U-238	3.62E-06	**3.62E-06**
4.65E+05	3.12E-06	1.60E-06	Th-230	6.07E-06	2.60E-06	Ra-226	1.05E-05	8.94E-06	Po-210	**8.82E-05**	2.82E-05	U-238	5.29E-06	**5.29E-06**
1.00E+06	4.10E-06	2.38E-06	Th-230	8.49E-06	3.88E-06	Ra-226	1.56E-05	1.33E-05	Po-210	**1.11E-04**	3.59E-05	Po-210	6.69E-06	**6.69E-06**
2.15E+06	4.37E-06	2.59E-06	Th-230	9.16E-06	4.23E-06	Ra-226	1.71E-05	1.45E-05	Po-210	**1.18E-04**	3.91E-05	Po-210	7.07E-06	**7.07E-06**
4.65E+06	4.37E-06	2.60E-06	Th-230	9.18E-06	4.24E-06	Ra-226	1.71E-05	1.46E-05	Po-210	**1.18E-04**	3.92E-05	Po-210	7.08E-06	**7.08E-06**
1.00E+07	4.36E-06	2.60E-06	Th-230	9.18E-06	4.24E-06	Ra-226	1.71E-05	1.46E-05	Po-210	**1.18E-04**	3.92E-05	Po-210	7.07E-06	**7.07E-06**
2.15E+07	4.35E-06	2.59E-06	Th-230	9.16E-06	4.23E-06	Ra-226	1.71E-05	1.45E-05	Po-210	**1.18E-04**	3.91E-05	Po-210	7.06E-06	**7.06E-06**
4.65E+07	4.32E-06	2.58E-06	Th-230	9.13E-06	4.21E-06	Ra-226	1.70E-05	1.45E-05	Po-210	**1.17E-04**	3.90E-05	Po-210	7.03E-06	**7.03E-06**
1.00E+08	4.26E-06	2.56E-06	Th-230	9.05E-06	4.18E-06	Ra-226	1.69E-05	1.44E-05	Po-210	**1.16E-04**	3.87E-05	Po-210	6.97E-06	**6.97E-06**

TABLE E8.29 Annual effective doses (Sv) and risks to nomadic inhabitants following gross erosion as a function of exposure pathway

	Inhalation			Ingestion of plants			Ingestion of meat			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	1.33E-06	1.17E-06	Am-241	7.20E-06	2.82E-06	H-3	1.67E-05	8.43E-06	Cs-137	**5.16E-05**	1.54E-05	Cs-137	3.10E-06	**3.10E-06**
1.00E+00	1.33E-06	1.17E-06	Am-241	6.94E-06	2.66E-06	H-3	1.62E-05	8.23E-06	Cs-137	**4.89E-05**	1.50E-05	Cs-137	2.93E-06	**2.93E-06**
2.15E+00	1.33E-06	1.17E-06	Am-241	6.66E-06	2.50E-06	H-3	1.56E-05	8.02E-06	Cs-137	**4.61E-05**	1.46E-05	Cs-137	2.77E-06	**2.77E-06**
4.65E+00	1.33E-06	1.16E-06	Am-241	6.10E-06	2.17E-06	H-3	1.45E-05	7.57E-06	Cs-137	**4.12E-05**	1.38E-05	Cs-137	2.47E-06	**2.47E-06**
1.00E+01	1.33E-06	1.15E-06	Am-241	5.11E-06	1.64E-06	Cs-137	1.25E-05	6.69E-06	Cs-137	**3.39E-05**	1.22E-05	Cs-137	2.03E-06	**2.03E-06**
2.15E+01	1.31E-06	1.13E-06	Am-241	3.60E-06	1.26E-06	Cs-137	9.58E-06	5.12E-06	Cs-137	**2.57E-05**	9.36E-06	Cs-137	1.54E-06	**1.54E-06**
4.65E+01	1.28E-06	1.09E-06	Am-241	1.93E-06	7.08E-07	Cs-137	6.56E-06	2.88E-06	Cs-137	**1.91E-05**	5.26E-06	Cs-137	1.15E-06	**1.15E-06**
1.00E+02	1.19E-06	9.98E-07	Am-241	7.86E-07	2.05E-07	Cs-137	4.59E-06	3.31E-06	Po-210	**1.48E-05**	5.72E-06	Po-210	8.89E-07	**8.89E-07**
2.15E+02	1.02E-06	8.30E-07	Am-241	4.07E-07	1.70E-07	Ra-226	3.74E-06	3.30E-06	Po-210	**1.27E-05**	5.71E-06	Po-210	7.64E-07	**7.64E-07**
4.65E+02	7.37E-07	5.57E-07	Am-241	3.48E-07	1.53E-07	Ra-226	3.31E-06	2.97E-06	Po-210	**1.14E-05**	5.13E-06	Po-210	6.85E-07	**6.85E-07**
1.00E+03	4.04E-07	2.36E-07	Am-241	2.89E-07	1.21E-07	Ra-226	2.63E-06	2.35E-06	Po-210	**9.51E-06**	4.07E-06	Po-210	5.71E-07	**5.71E-07**
2.15E+03	1.88E-07	4.82E-08	U-238	2.01E-07	7.35E-08	Ra-226	1.60E-06	1.43E-06	Po-210	**7.10E-06**	3.42E-06	U-238	4.26E-07	**4.26E-07**
4.65E+03	1.37E-07	4.82E-08	U-238	1.11E-07	4.18E-08	Ra-228	5.49E-07	4.87E-07	Po-210	**4.92E-06**	3.42E-06	U-238	2.95E-07	**2.95E-07**
1.00E+04	1.40E-07	4.82E-08	U-238	7.06E-08	4.18E-08	Ra-228	6.65E-08	5.30E-08	Po-210	**4.00E-06**	3.42E-06	U-238	2.40E-07	**2.40E-07**
2.15E+04	1.66E-07	4.82E-08	U-238	6.87E-08	4.18E-08	Ra-228	3.50E-08	2.45E-08	Po-210	**4.09E-06**	3.42E-06	U-238	2.46E-07	**2.46E-07**
4.65E+04	2.14E-07	6.17E-08	Ac-227	7.86E-08	4.18E-08	Ra-228	1.31E-07	1.10E-07	Po-210	**4.60E-06**	3.42E-06	U-238	2.76E-07	**2.76E-07**
1.00E+05	3.00E-07	8.67E-08	Ac-227	1.13E-07	4.18E-08	Ra-228	4.98E-07	4.39E-07	Po-210	**5.91E-06**	3.42E-06	U-238	3.55E-07	**3.55E-07**
2.15E+05	4.60E-07	1.65E-07	Th-230	2.11E-07	7.31E-08	Ra-226	1.57E-06	1.40E-06	Po-210	**9.08E-06**	3.42E-06	U-238	5.45E-07	**5.45E-07**
4.65E+05	7.24E-07	3.71E-07	Th-230	3.90E-07	1.66E-07	Ra-226	3.57E-06	3.19E-06	Po-210	**1.45E-05**	5.52E-06	Po-210	8.70E-07	**8.70E-07**
1.00E+06	9.50E-07	5.51E-07	Th-230	5.45E-07	2.48E-07	Ra-226	5.31E-06	4.75E-06	Po-210	**1.91E-05**	8.22E-06	Po-210	1.15E-06	**1.15E-06**
2.15E+06	1.01E-06	6.01E-07	Th-230	5.88E-07	2.70E-07	Ra-226	5.79E-06	5.18E-06	Po-210	**2.04E-05**	8.97E-06	Po-210	1.22E-06	**1.22E-06**
4.65E+06	1.01E-06	6.03E-07	Th-230	5.89E-07	2.71E-07	Ra-226	5.80E-06	5.20E-06	Po-210	**2.04E-05**	8.99E-06	Po-210	1.22E-06	**1.22E-06**
1.00E+07	1.01E-06	6.02E-07	Th-230	5.89E-07	2.71E-07	Ra-226	5.80E-06	5.19E-06	Po-210	**2.04E-05**	8.99E-06	Po-210	1.22E-06	**1.22E-06**
2.15E+07	1.01E-06	6.01E-07	Th-230	5.88E-07	2.70E-07	Ra-226	5.79E-06	5.19E-06	Po-210	**2.03E-05**	8.97E-06	Po-210	1.22E-06	**1.22E-06**
4.65E+07	1.00E-06	5.99E-07	Th-230	5.86E-07	2.69E-07	Ra-226	5.77E-06	5.17E-06	Po-210	**2.02E-05**	8.94E-06	Po-210	1.21E-06	**1.21E-06**
1.00E+08	9.88E-07	5.94E-07	Th-230	5.81E-07	2.67E-07	Ra-226	5.72E-06	5.12E-06	Po-210	**2.01E-05**	8.86E-06	Po-210	1.20E-06	**1.20E-06**

TABLE E8.30 Annual effective dose (Sv) and risks to settler inhabitants following site flooding as a function of exposure pathway

	Inhalation			Ingestion of plants			Ingestion of meat			Total dose			Risks	
Time	Dose	Max	RN	Dose	Max	RN	Dose	Max	RN	Dose	Max	RN	Conditional	Annual
0.00E+00	4.01E-05	3.54E-05	Am-241	2.63E-04	1.10E-04	H-3	3.39E-04	2.20E-04	Cs-137	1.24E-03	4.40E-04	Co-60	7.44E-05	7.44E-05
1.00E+00	4.01E-05	3.53E-05	Am-241	2.54E-04	1.04E-04	H-3	3.29E-04	2.15E-04	Cs-137	1.17E-03	4.16E-04	Cs-137	6.99E-05	6.99E-05
2.15E+00	4.01E-05	3.53E-05	Am-241	2.45E-04	9.71E-05	H-3	3.20E-04	2.09E-04	Cs-137	1.09E-03	4.05E-04	Cs-137	6.54E-05	6.54E-05
4.65E+00	4.01E-05	3.51E-05	Am-241	2.26E-04	8.44E-05	H-3	3.01E-04	1.97E-04	Cs-137	9.54E-04	3.83E-04	Cs-137	5.72E-05	5.72E-05
1.00E+01	4.00E-05	3.48E-05	Am-241	1.92E-04	6.25E-05	H-3	2.67E-04	1.74E-04	Cs-137	7.53E-04	3.38E-04	Cs-137	4.52E-05	4.52E-05
2.15E+01	3.97E-05	3.42E-05	Am-241	1.43E-04	3.89E-05	Cs-137	2.14E-04	1.34E-04	Cs-137	5.34E-04	2.59E-04	Cs-137	3.20E-05	3.20E-05
4.65E+01	3.85E-05	3.29E-05	Am-241	8.97E-05	2.19E-05	Cs-137	1.51E-04	7.51E-05	Cs-137	3.54E-04	1.46E-04	Cs-137	2.12E-05	2.12E-05
1.00E+02	3.59E-05	3.02E-05	Am-241	5.49E-05	1.95E-05	Ra-226	1.00E-04	6.49E-05	Po-210	2.30E-04	7.50E-05	Po-210	1.38E-05	1.38E-05
2.15E+02	3.07E-05	2.51E-05	Am-241	4.24E-05	1.86E-05	Ra-226	7.76E-05	6.47E-05	Po-210	1.76E-04	7.48E-05	Po-210	1.05E-05	1.05E-05
4.65E+02	2.23E-05	1.68E-05	Am-241	3.81E-05	1.67E-05	Ra-226	6.83E-05	5.82E-05	Po-210	1.50E-04	6.72E-05	Po-210	9.01E-06	9.01E-06
1.00E+03	1.22E-05	7.12E-06	Am-241	3.16E-05	1.32E-05	Ra-226	5.42E-05	4.62E-05	Po-210	1.15E-04	5.33E-05	Po-210	6.91E-06	6.91E-06
2.15E+03	5.68E-06	1.46E-06	U-238	2.19E-05	8.04E-06	Ra-226	3.30E-05	2.80E-05	Po-210	7.15E-05	3.24E-05	Po-210	4.29E-06	4.29E-06
4.65E+03	4.15E-06	1.46E-06	U-238	1.22E-05	4.58E-06	Ra-228	1.14E-05	9.55E-06	Po-210	3.23E-05	1.10E-05	Po-210	1.94E-06	1.94E-06
1.00E+04	4.24E-06	1.46E-06	U-238	7.69E-06	4.58E-06	Ra-228	1.45E-06	1.04E-06	Po-210	1.51E-05	5.94E-06	Ra-228	9.04E-07	9.04E-07
2.15E+04	5.01E-06	1.46E-06	U-238	7.48E-06	4.58E-06	Ra-228	8.11E-07	4.81E-07	Po-210	1.48E-05	5.94E-06	Ra-228	8.89E-07	8.89E-07
4.65E+04	6.48E-06	1.86E-06	Ac-227	8.56E-06	4.58E-06	Ra-228	2.81E-06	2.16E-06	Po-210	2.00E-05	5.94E-06	Ra-228	1.20E-06	1.20E-06
1.00E+05	9.05E-06	2.62E-06	Ac-227	1.23E-05	4.58E-06	Ra-228	1.04E-05	8.61E-06	Po-210	3.62E-05	9.94E-06	Po-210	2.17E-06	2.17E-06
2.15E+05	1.39E-05	4.98E-06	Th-230	2.30E-05	8.00E-06	Ra-226	3.25E-05	2.75E-05	Po-210	8.05E-05	3.18E-05	Po-210	4.83E-06	4.83E-06
4.65E+05	2.19E-05	1.12E-05	Th-230	4.25E-05	1.82E-05	Ra-226	7.36E-05	6.26E-05	Po-210	1.61E-04	7.23E-05	Po-210	9.68E-06	9.68E-06
1.00E+06	2.87E-05	1.67E-05	Th-230	5.95E-05	2.71E-05	Ra-226	1.10E-04	9.32E-05	Po-210	2.32E-04	1.08E-04	Po-210	1.39E-05	1.39E-05
2.15E+06	3.06E-05	1.81E-05	Th-230	6.41E-05	2.96E-05	Ra-226	1.19E-04	1.02E-04	Po-210	2.51E-04	1.17E-04	Po-210	1.51E-05	1.51E-05
4.65E+06	3.06E-05	1.82E-05	Th-230	6.43E-05	2.97E-05	Ra-226	1.20E-04	1.02E-04	Po-210	2.52E-04	1.18E-04	Po-210	1.51E-05	1.51E-05
1.00E+07	3.05E-05	1.82E-05	Th-230	6.42E-05	2.96E-05	Ra-226	1.20E-04	1.02E-04	Po-210	2.51E-04	1.18E-04	Po-210	1.51E-05	1.51E-05
2.15E+07	3.04E-05	1.82E-05	Th-230	6.41E-05	2.96E-05	Ra-226	1.19E-04	1.02E-04	Po-210	2.51E-04	1.17E-04	Po-210	1.51E-05	1.51E-05
4.65E+07	3.02E-05	1.81E-05	Th-230	6.39E-05	2.95E-05	Ra-226	1.19E-04	1.01E-04	Po-210	2.50E-04	1.17E-04	Po-210	1.50E-05	1.50E-05
1.00E+08	2.98E-05	1.79E-05	Th-230	6.34E-05	2.92E-05	Ra-226	1.18E-04	1.00E-04	Po-210	2.48E-04	1.16E-04	Po-210	1.49E-05	1.49E-05

TABLE E8.31 Annual effective doses (Sv) and risks to nomadic inhabitants following site flooding as a function of exposure pathway

	Inhalation			Ingestion of plants			Ingestion of meat			Total dose			Risks	
Time	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	9.29E-06	8.20E-06	Am-241	5.04E-05	1.97E-05	H-3	1.17E-04	5.90E-05	Cs-137	**3.20E-04**	1.07E-04	Cs-137	1.92E-05	**1.92E-05**
1.00E+00	9.29E-06	8.19E-06	Am-241	4.86E-05	1.86E-05	H-3	1.13E-04	5.76E-05	Cs-137	**3.01E-04**	1.05E-04	Cs-137	1.81E-05	**1.81E-05**
2.15E+00	9.29E-06	8.18E-06	Am-241	4.66E-05	1.75E-05	H-3	1.09E-04	5.61E-05	Cs-137	**2.82E-04**	1.02E-04	Cs-137	1.69E-05	**1.69E-05**
4.65E+00	9.29E-06	8.14E-06	Am-241	4.27E-05	1.52E-05	H-3	1.01E-04	5.30E-05	Cs-137	**2.48E-04**	9.65E-05	Cs-137	1.49E-05	**1.49E-05**
1.00E+01	9.28E-06	8.07E-06	Am-241	3.57E-05	1.15E-05	Cs-137	8.74E-05	4.68E-05	Cs-137	**1.97E-04**	8.53E-05	Cs-137	1.18E-05	**1.18E-05**
2.15E+01	9.20E-06	7.93E-06	Am-241	2.52E-05	8.81E-06	Cs-137	6.70E-05	3.59E-05	Cs-137	**1.41E-04**	6.53E-05	Cs-137	8.44E-06	**8.44E-06**
4.65E+01	8.93E-06	7.62E-06	Am-241	1.35E-05	4.95E-06	Cs-137	4.59E-05	2.02E-05	Cs-137	**9.47E-05**	3.67E-05	Cs-137	5.68E-06	**5.68E-06**
1.00E+02	8.32E-06	6.99E-06	Am-241	5.50E-06	1.44E-06	Cs-137	3.21E-05	2.32E-05	Po-210	**6.47E-05**	2.81E-05	Po-210	3.88E-06	**3.88E-06**
2.15E+02	7.12E-06	5.81E-06	Am-241	2.85E-06	1.19E-06	Ra-226	2.62E-05	2.31E-05	Po-210	**5.12E-05**	2.80E-05	Po-210	3.07E-06	**3.07E-06**
4.65E+02	5.16E-06	3.90E-06	Am-241	2.44E-06	1.07E-06	Ra-226	2.32E-05	2.08E-05	Po-210	**4.38E-05**	2.52E-05	Po-210	2.63E-06	**2.63E-06**
1.00E+03	2.83E-06	1.65E-06	Am-241	2.03E-06	8.47E-07	Ra-226	1.84E-05	1.65E-05	Po-210	**3.33E-05**	2.00E-05	Po-210	2.00E-06	**2.00E-06**
2.15E+03	1.32E-06	3.38E-07	U-238	1.41E-06	5.14E-07	Ra-226	1.12E-05	1.00E-05	Po-210	**2.02E-05**	1.21E-05	Po-210	1.21E-06	**1.21E-06**
4.65E+03	9.61E-07	3.38E-07	U-238	7.80E-07	2.93E-07	Ra-228	3.85E-06	3.41E-06	Po-210	**8.29E-06**	4.13E-06	Po-210	4.97E-07	**4.97E-07**
1.00E+04	9.82E-07	3.38E-07	U-238	4.94E-07	2.93E-07	Ra-228	4.65E-07	3.71E-07	Po-210	**3.07E-06**	8.39E-07	Ra-228	1.84E-07	**1.84E-07**
2.15E+04	1.16E-06	3.38E-07	U-238	4.81E-07	2.93E-07	Ra-228	2.45E-07	1.72E-07	Po-210	**2.98E-06**	8.39E-07	Ra-228	1.79E-07	**1.79E-07**
4.65E+04	1.50E-06	4.32E-07	Ac-227	5.50E-07	2.93E-07	Ra-228	9.17E-07	7.72E-07	Po-210	**4.50E-06**	9.36E-07	Po-210	2.70E-07	**2.70E-07**
1.00E+05	2.10E-06	6.07E-07	Ac-227	7.93E-07	2.93E-07	Ra-228	3.48E-06	3.07E-06	Po-210	**9.32E-06**	3.73E-06	Po-210	5.59E-07	**5.59E-07**
2.15E+05	3.22E-06	1.15E-06	Th-230	1.48E-06	5.12E-07	Ra-226	1.10E-05	9.82E-06	Po-210	**2.26E-05**	1.19E-05	Po-210	1.35E-06	**1.35E-06**
4.65E+05	5.07E-06	2.60E-06	Th-230	2.73E-06	1.16E-06	Ra-226	2.50E-05	2.23E-05	Po-210	**4.68E-05**	2.71E-05	Po-210	2.81E-06	**2.81E-06**
1.00E+06	6.65E-06	3.86E-06	Th-230	3.82E-06	1.74E-06	Ra-226	3.71E-05	3.33E-05	Po-210	**6.79E-05**	4.03E-05	Po-210	4.07E-06	**4.07E-06**
2.15E+06	7.08E-06	4.21E-06	Th-230	4.12E-06	1.89E-06	Ra-226	4.05E-05	3.63E-05	Po-210	**7.37E-05**	4.40E-05	Po-210	4.42E-06	**4.42E-06**
4.65E+06	7.09E-06	4.22E-06	Th-230	4.13E-06	1.90E-06	Ra-226	4.06E-05	3.64E-05	Po-210	**7.39E-05**	4.41E-05	Po-210	4.43E-06	**4.43E-06**
1.00E+07	7.07E-06	4.21E-06	Th-230	4.12E-06	1.90E-06	Ra-226	4.06E-05	3.64E-05	Po-210	**7.38E-05**	4.41E-05	Po-210	4.43E-06	**4.43E-06**
2.15E+07	7.05E-06	4.21E-06	Th-230	4.12E-06	1.89E-06	Ra-226	4.05E-05	3.63E-05	Po-210	**7.36E-05**	4.40E-05	Po-210	4.42E-06	**4.42E-06**
4.65E+07	7.01E-06	4.19E-06	Th-230	4.10E-06	1.89E-06	Ra-226	4.04E-05	3.62E-05	Po-210	**7.33E-05**	4.38E-05	Po-210	4.40E-06	**4.40E-06**
1.00E+08	6.92E-06	4.16E-06	Th-230	4.07E-06	1.87E-06	Ra-226	4.00E-05	3.59E-05	Po-210	**7.27E-05**	4.35E-05	Po-210	4.36E-06	**4.36E-06**

TABLE E8.32 Annual effective doses (Sv) and risks arising from consumption of contaminated well water

	Ingestion of water			Risks	
Time	**Dose**	**Max**	**RN**	**Conditional**	**Annual**
0.00E+00	**4.90E-03**	2.76E-03	U-238	2.94E-04	**2.94E-07**
1.00E+00	**4.86E-03**	2.76E-03	U-238	2.91E-04	**2.91E-07**
2.15E+00	**4.83E-03**	2.76E-03	U-238	2.90E-04	**2.90E-07**
4.65E+00	**4.79E-03**	2.76E-03	U-238	2.87E-04	**2.87E-07**
1.00E+01	**4.73E-03**	2.76E-03	U-238	2.84E-04	**2.84E-07**
2.15E+01	**4.67E-03**	2.76E-03	U-238	2.80E-04	**2.80E-07**
4.65E+01	**4.66E-03**	2.76E-03	U-238	2.80E-04	**2.80E-07**
1.00E+02	**4.65E-03**	2.76E-03	U-238	2.79E-04	**2.79E-07**
2.15E+02	**4.53E-03**	2.76E-03	U-238	2.72E-04	**2.72E-07**
4.65E+02	**4.31E-03**	2.76E-03	U-238	2.58E-04	**2.58E-07**
1.00E+03	**3.96E-03**	2.76E-03	U-238	2.38E-04	**2.38E-07**
2.15E+03	**3.51E-03**	2.76E-03	U-238	2.11E-04	**2.11E-07**
4.65E+03	**3.11E-03**	2.76E-03	U-238	1.87E-04	**1.87E-07**
1.00E+04	**2.97E-03**	2.76E-03	U-238	1.78E-04	**1.78E-07**
2.15E+04	**3.06E-03**	2.76E-03	U-238	1.83E-04	**1.83E-07**
4.65E+04	**3.29E-03**	2.76E-03	U-238	1.98E-04	**1.98E-07**
1.00E+05	**3.82E-03**	2.76E-03	U-238	2.29E-04	**2.29E-07**
2.15E+05	**4.88E-03**	2.76E-03	U-238	2.93E-04	**2.93E-07**
4.65E+05	**6.51E-03**	2.76E-03	U-238	3.91E-04	**3.91E-07**
1.00E+06	**7.84E-03**	2.83E-03	U-234	4.70E-04	**4.70E-07**
2.15E+06	**8.19E-03**	3.00E-03	U-234	4.92E-04	**4.92E-07**
4.65E+06	**8.20E-03**	3.00E-03	U-234	4.92E-04	**4.92E-07**
1.00E+07	**8.19E-03**	3.00E-03	U-234	4.91E-04	**4.91E-07**
2.15E+07	**8.18E-03**	2.99E-03	U-234	4.91E-04	**4.91E-07**
4.65E+07	**8.14E-03**	2.98E-03	U-234	4.88E-04	**4.88E-07**
1.00E+08	**8.07E-03**	2.96E-03	U-234	4.84E-04	**4.84E-07**

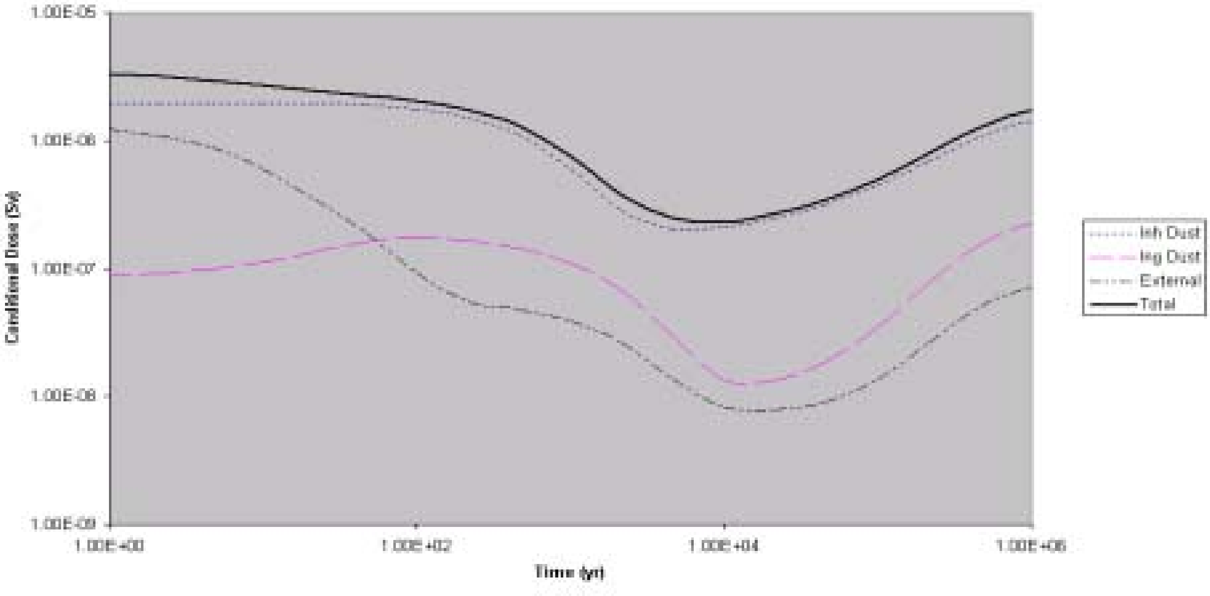

FIGURE E8.5
Conditional doses for borehole drilling

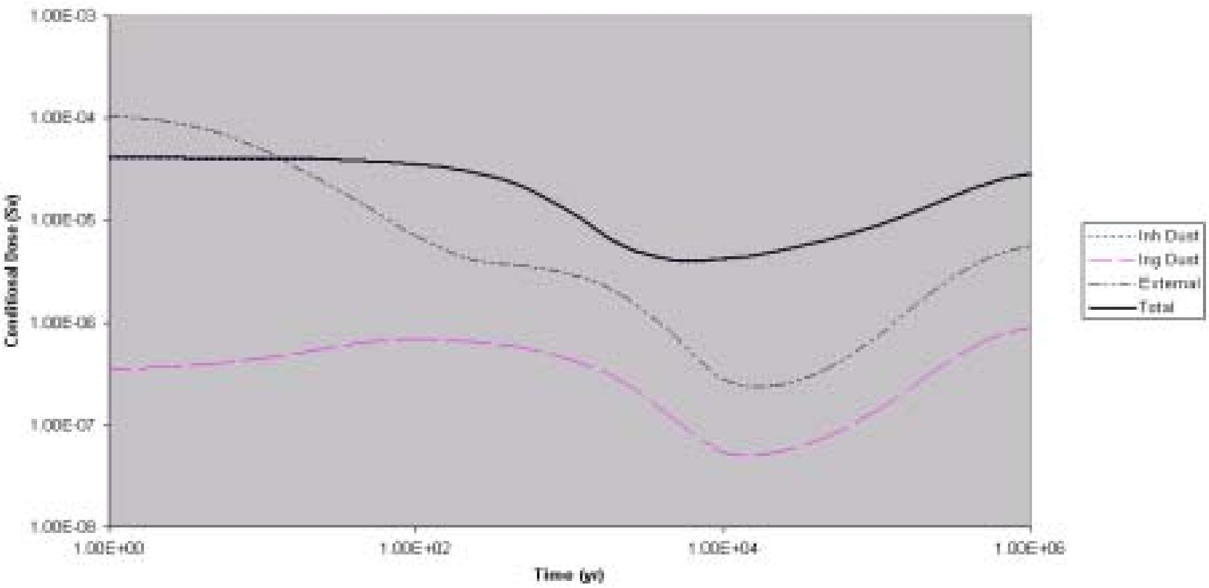

FIGURE E8.6
Conditional doses for bulk excavation

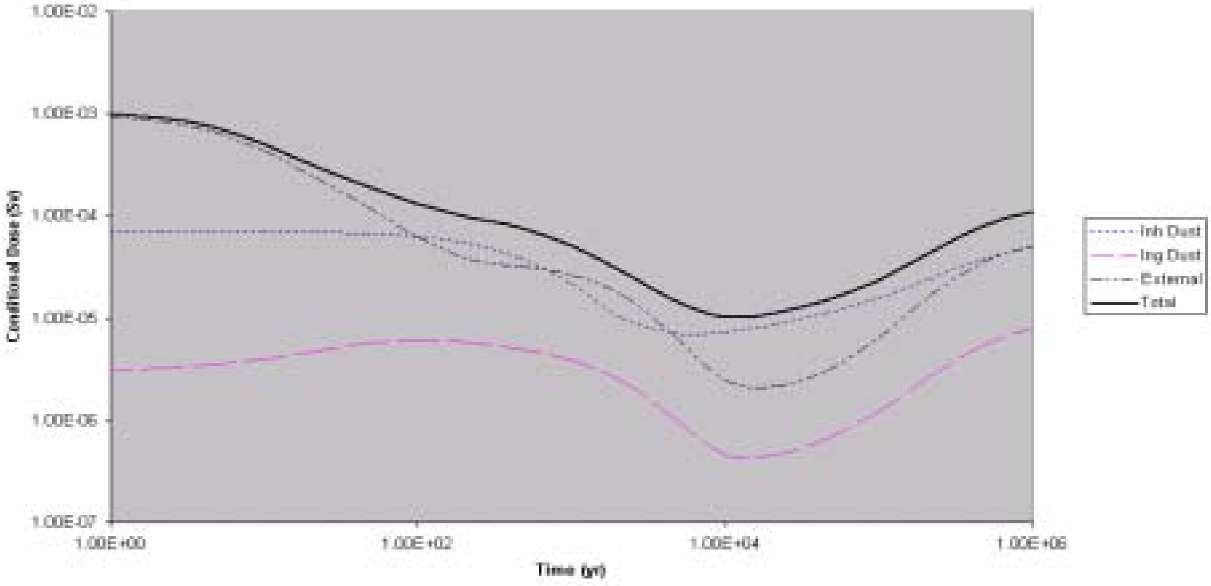

FIGURE E8.7
Conditional doses to road builders

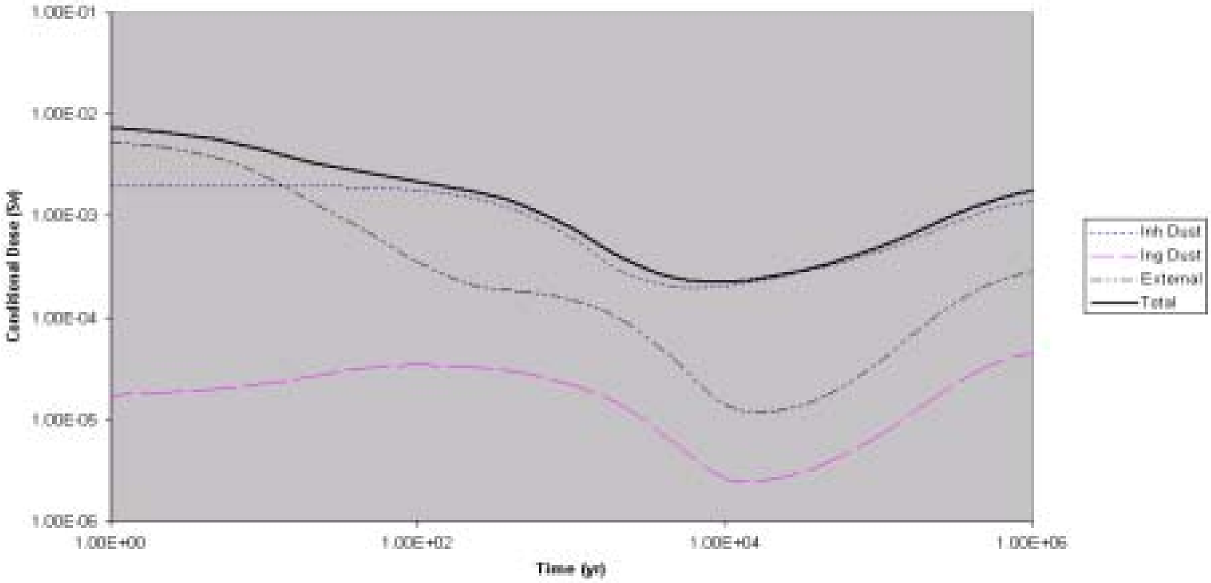

FIGURE E8.8
Conditional doses to archaeologists

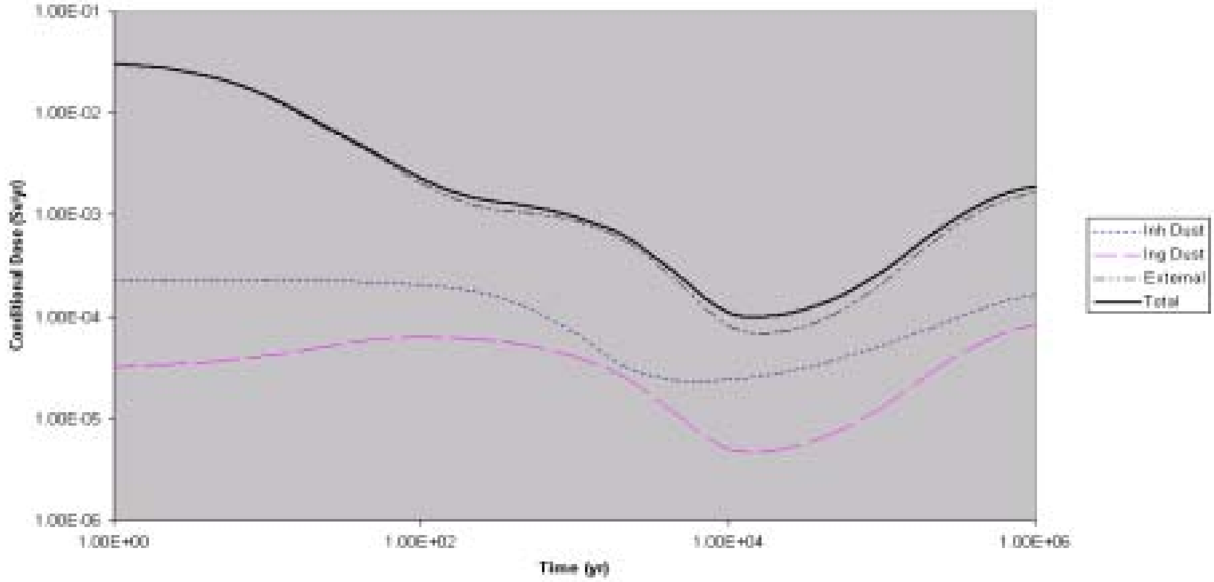

FIGURE E8.9
Conditional doses for longer-term exposure to settlers

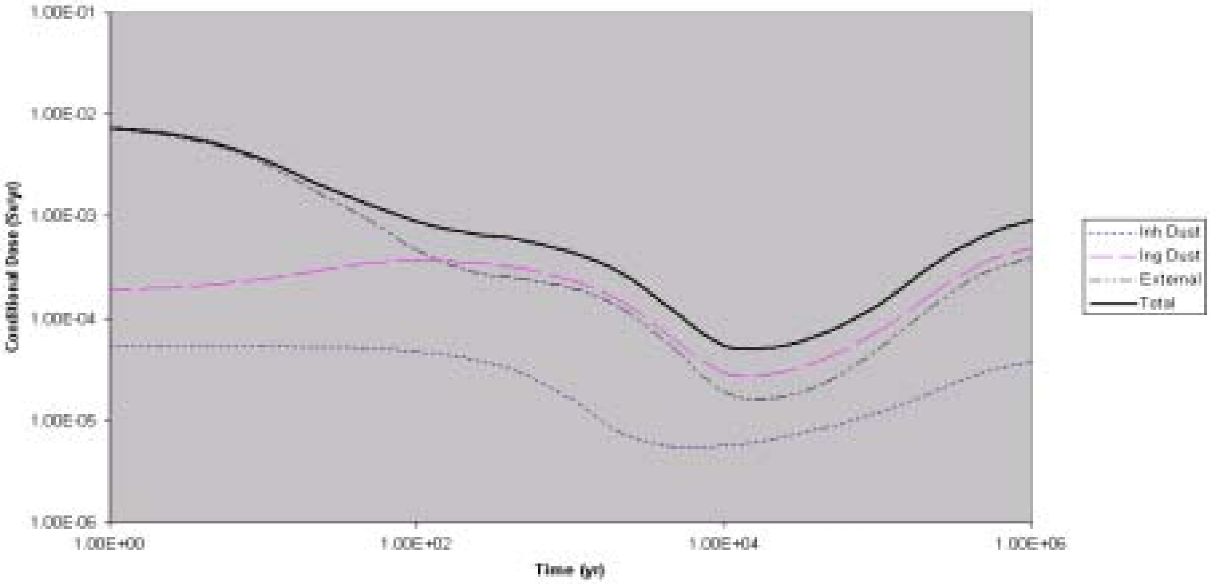

FIGURE E8.10
Conditional doses for longer-term exposure to nomads

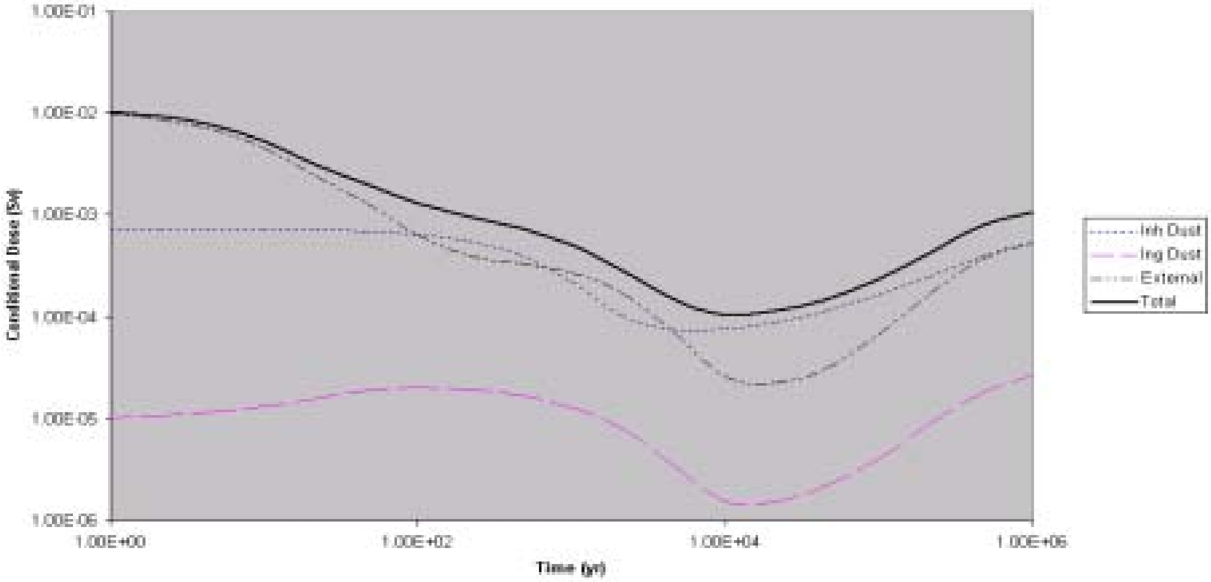

FIGURE E8.11
Conditional doses to settlers in the rocket crash scenario

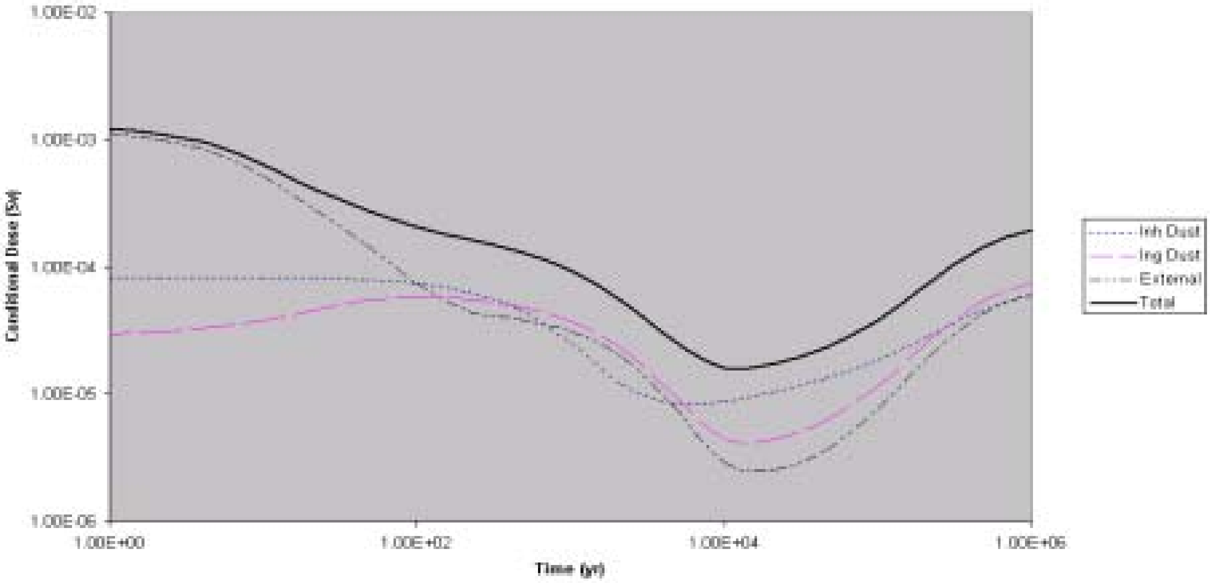

FIGURE E8.12
Conditional doses to nomads in the rocket crash scenario

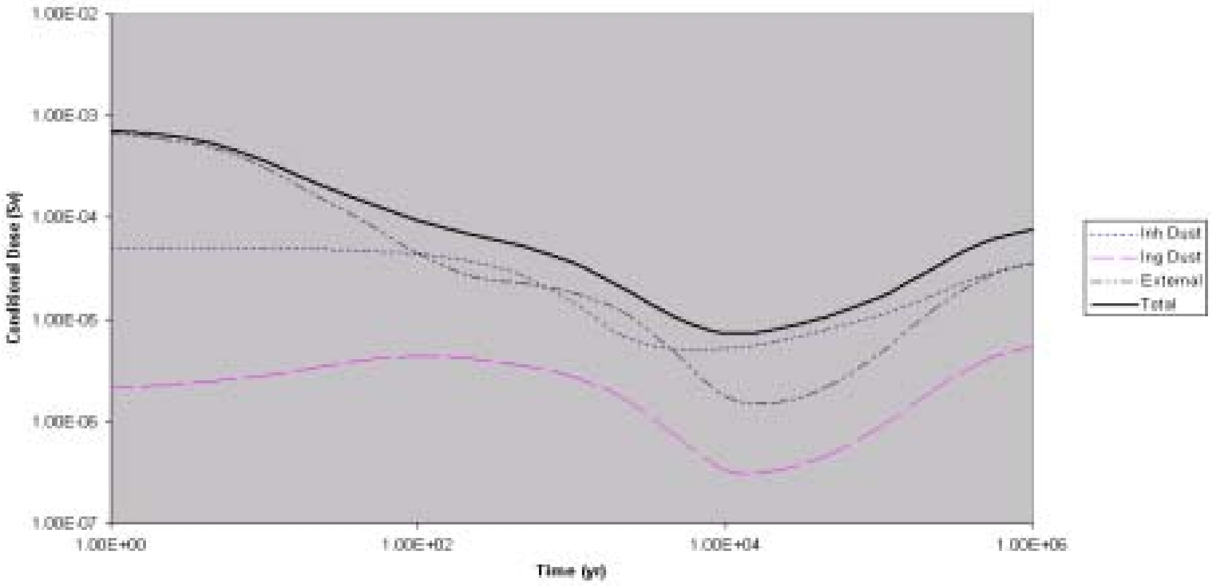

FIGURE E8.13
Conditional doses for aircraft crash scenario

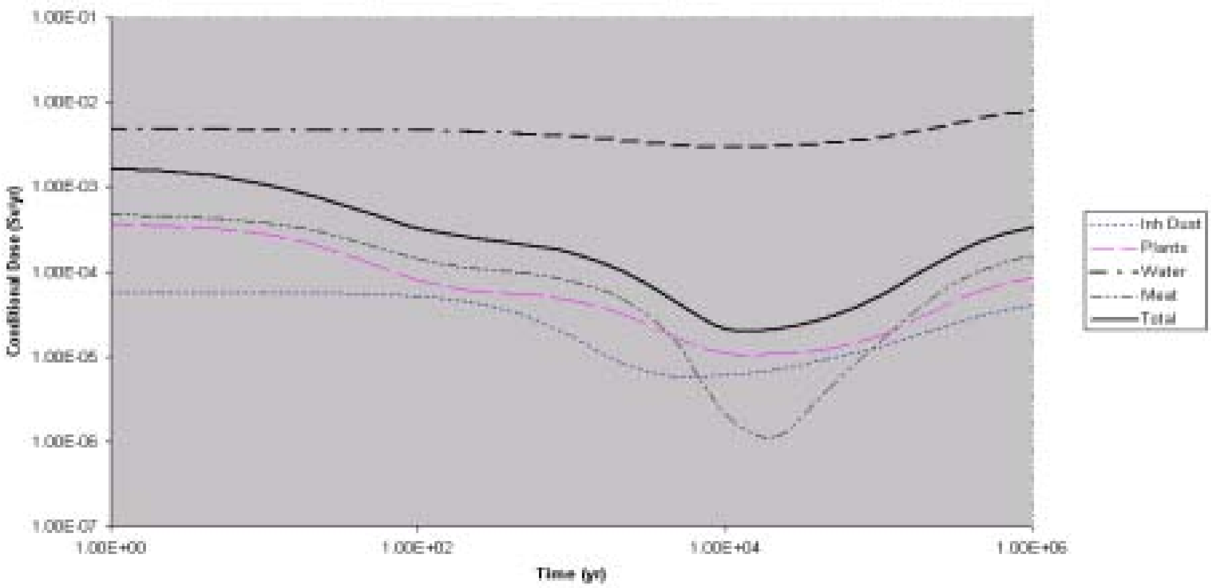

FIGURE E8.14
Conditional doses to settlers in the wetter climate scenario (including well water doses)

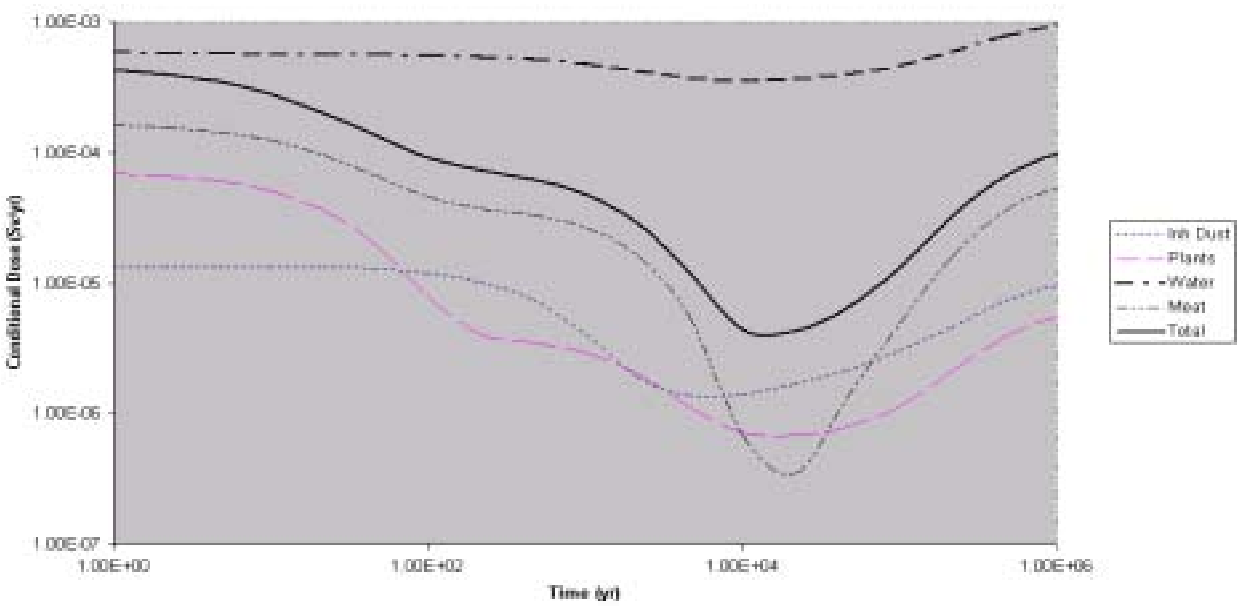

FIGURE E8.15
Conditional doses to nomads in the wetter climate scenario (including well water doses)

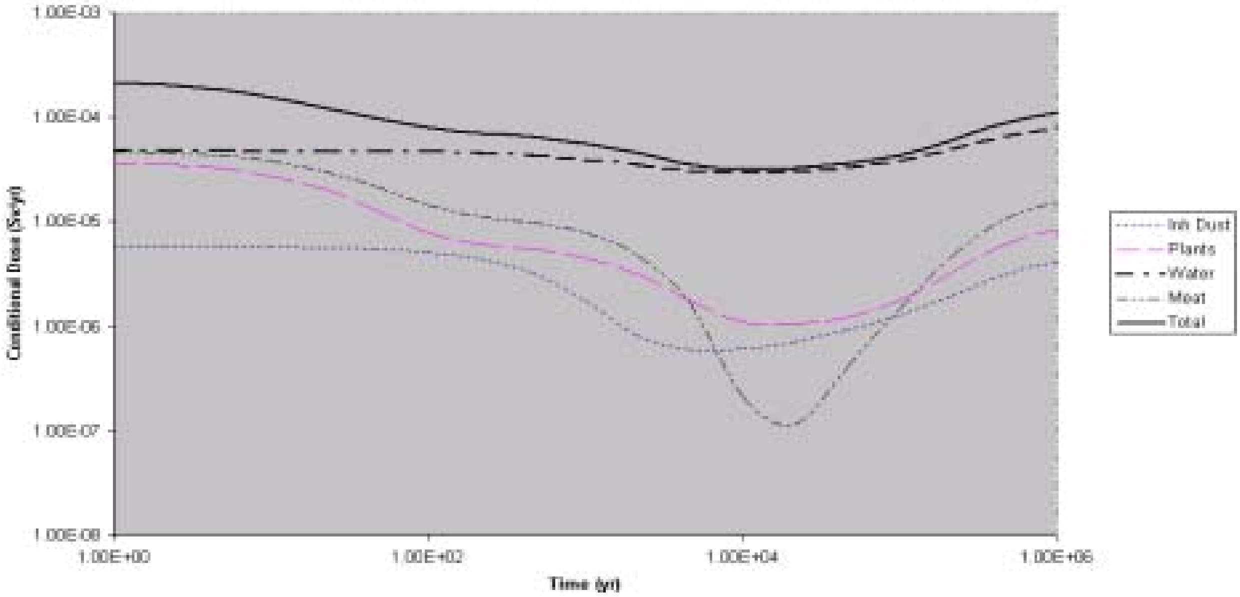

FIGURE E8.16
Conditional doses to settlers in the gross erosion scenario (including well water doses)

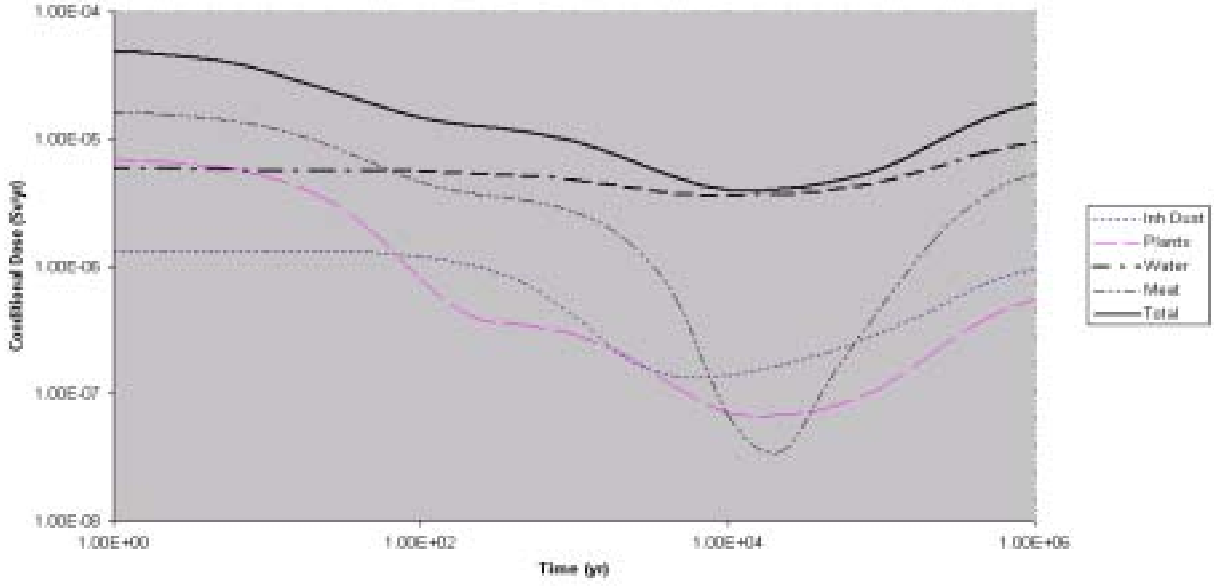

FIGURE E8.17
Conditional doses to nomads in the gross erosion scenario (including well water doses)

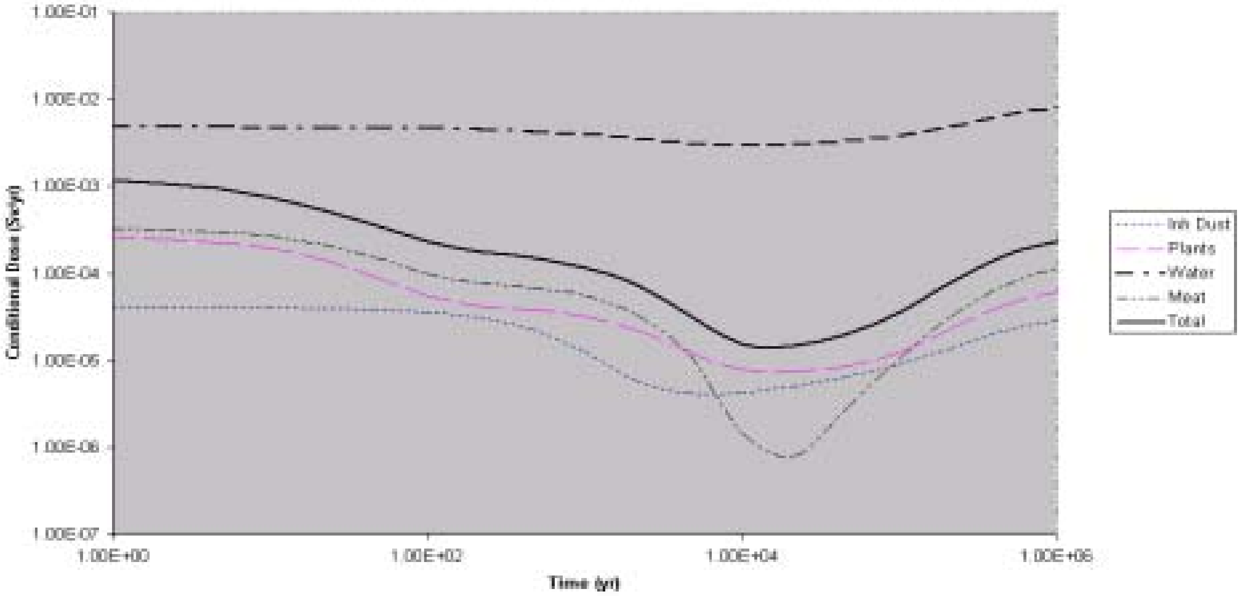

FIGURE E8.18
Conditional doses to settlers in the bathtubbing scenario (including well water doses)

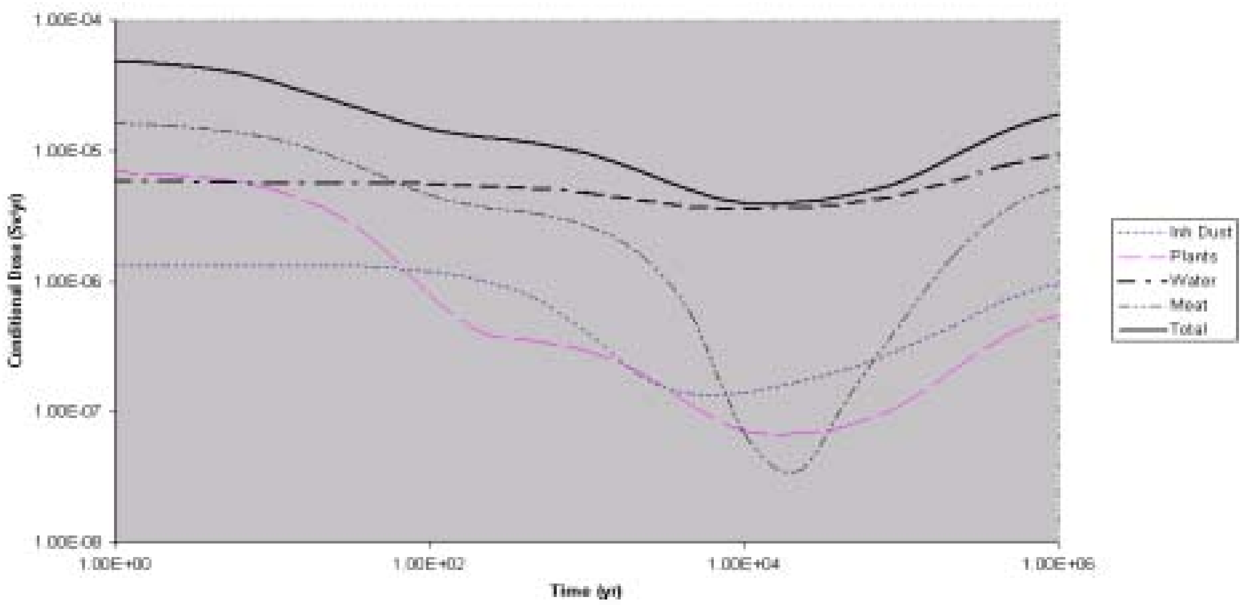

FIGURE E8.19
Conditional doses to nomads in the site flooding scenario (including well water doses)

E8.6.1 Borehole Drilling

For the borehole drillers, the maximum doses would be attained if the intrusion occurred immediately after the institutional period of control finishes. This dose is:

D(borehole) = 1.7 x 10^{-6} Sv

with the most significant radionuclide being ^{241}Am. Inhalation of contaminated dust is the most significant exposure pathway, with ^{241}Am again being the most significant contributor. At later times, ^{230}Th and its decay products ^{226}Ra and ^{210}Po provide the largest contribution to dose.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of borehole drilling, the annual individual risk is:

R(borehole) = 1.0 x 10^{-11}/yr

for an intrusion immediately after the end of the period of institutional control. This risk value is comfortably below the risk target of 1 x 10^{-6}/yr.

E8.6.2 Bulk Excavation

For the excavation workers, the maximum doses would be attained if the intrusion occurred immediately after the institutional period of control finishes. This dose is:

D(excavation) = 3.5 x 10^{-5} Sv

with the most significant radionuclide being ^{241}Am. Inhalation of contaminated dust is the most significant exposure pathway, with ^{241}Am again being the most significant contributor. At later times, ^{230}Th and its decay products ^{226}Ra and ^{210}Po provide the largest contribution to dose.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of borehole drilling, the annual individual risk is:

R(excavation) = 2 x 10^{-10}/yr

for an intrusion immediately after the end of the period of institutional control. This risk value is comfortably below the risk target of 1 x 10^{-6}/yr.

E8.6.3 Road Building

For the road builders, the maximum doses would be attained if the building work occurred immediately after the institutional period of control finishes. This dose is:

D(road building) = 9.6 x 10^{-5} Sv

with the most significant radionuclide being ^{241}Am. Inhalation of contaminated dust is the most significant exposure pathway, with ^{241}Am again being the most significant contributor. At later times, ^{226}Ra and ^{210}Po (and to a lesser extent ^{230}Th) provide the largest contribution to dose.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of road building, the annual individual risk is:

R(road building) = 1.2 x 10^{-10}/yr

for an intrusion immediately after the end of the period of institutional control. This risk value is comfortably below the risk target of 1 x 10^{-6}/yr. Thus, even though the assessed dose is close to that specified as the public dose limit by many authorities, the low probability of occurrence ensures that the individual risks are small.

In addition, it should be noted that road foundations are unlikely to penetrate the wastes until erosion has occurred for at least 4000 years, at which point assessed doses drop to around 1.5 x 10^{-5} Sv.

E8.6.4 Archaeological Activity

For the archaeologists, the maximum doses would be attained if the archaeological work occurred immediately after the institutional period of control finishes. This dose is:

D(archaeology) = 1.7 x 10^{-3} Sv

with the most significant radionuclide being ^{241}Am. Inhalation of contaminated dust is the most significant exposure pathway, with ^{241}Am again being the most significant contributor. At later times, ^{230}Th and its decay products ^{226}Ra and ^{210}Po provide the largest contribution to dose.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of archaeological digging, the annual individual risk is:

R(archaeology) = 1.1 x 10^{-8}/yr

for an intrusion immediately after the end of the period of institutional control. This risk value is comfortably below the risk target of 1 x 10^{-6}/yr. Thus, even though the assessed dose is considerably in excess of that specified as the public dose limit by many authorities, the low probability of occurrence ensures that the individual risks are small.

It should noted that the guidance provided in ICRP 81 (1988) suggests that, when dose rates are in excess of 10 mSv/yr, consideration should be given to optimising the repository design, so as to make the assessed doses as low as reasonably achievable.

E8.6.5 Long Term Exposure Following Excavation

For future inhabitants who make use of excavated materials, the maximum doses would be attained if the excavation intrusion occurred immediately after the institutional period of control finishes. This dose would be attained in the earliest years of material usage, and is around:

D(long term, settler) = 1.5 x 10^{-3} Sv/yr
D(long term, nomad) = 6.8 x 10^{-4} Sv/yr

with the most significant radionuclide being ^{226}Ra. External irradiation is the most significant exposure pathway, with ^{226}Ra being the most significant contributor, though both the ingestion and inhalation of dust pathways are important too (with ^{241}Am being the most significant contributor in both cases). At later times, ^{230}Th and its decay products ^{226}Ra and ^{210}Po provide the largest contribution to dose.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of such usage of excavated materials, the annual individual risk is:

R(long term, settler) = 8.9 x 10^{-8}/yr
R(long term, nomad) = 4.1 x 10^{-8}/yr

for an intrusion immediately after the end of the period of institutional control. This risk value is comfortably below the risk target of 1 x 10^{-6}/yr. Thus, even though the assessed dose is considerably in excess of that specified as the public dose limit by many authorities, the low probability of occurrence ensures that the individual risks are small.

It should noted that the guidance provided in ICRP 81 (1988) suggests that, when doses are in excess of 10 mSv/yr, consideration should be given to optimising the repository design, so as to make the assessed doses as low as reasonably achievable.

E8.6.6 Rocket or Weapon Crash

For the children who play on exposed wastes after a rocket crash at the repository site, the maximum doses would be attained if the crash occurred immediately after the institutional period of control finishes. This dose is:

D(weapon, settler) = 9.6 x 10^{-4} Sv
D(weapon, nomad) = 1.6 x 10^{-4} Sv

with the most significant radionuclide being ^{241}Am. Inhalation of contaminated dust is the most significant exposure pathway, with ^{241}Am again being the most significant contributor. External irradiation (^{226}Ra) is also a significant exposure pathway. At later times, ^{230}Th and its decay products ^{226}Ra and ^{210}Po provide the largest contribution to dose.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of rocket crashes, the annual individual risk is:

R(weapon, settler) = 1.7 x 10^{-9}/yr
R(weapon, nomad) = 3 x 10^{-10}/yr

for a rocket crash immediately after the end of the period of institutional control. This risk value is comfortably below the risk target of 1 x 10^{-6}/yr. Thus, even though the assessed dose is considerably in excess of that specified as the public dose limit by many authorities, the low probability of occurrence ensures that the individual risks are small. In fact, in the case of the rocket crash, the true frequency of occurrence is likely to be considerably less than the value of 3 x 10^{-5} /yr assumed in this study.

It should noted that the guidance provided in ICRP 81 (1988) suggests that, when doses are in excess of 10 mSv, consideration should be given to optimising the repository design, so as to make the assessed doses as low as reasonably achievable.

E8.6.7 Aircraft Crash

For the aircraft recovery team that clears up aircraft debris lying on exposed wastes after an aircraft crash, the maximum doses would be attained if the crash occurred immediately after the institutional period of control finishes. This dose is:

D(aircraft) = 6.9×10^{-5} Sv

with the most significant radionuclide being ^{241}Am. Inhalation of contaminated dust is the most significant exposure pathway, with ^{241}Am again being the most significant contributor. External irradiation (^{226}Ra) is also a significant exposure pathway. At later times, ^{230}Th and its decay products ^{226}Ra and ^{210}Po provide the largest contribution to dose.

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of aircraft crashes, the annual individual risk is:

R(aircraft) = 2.9×10^{-13}/yr

for an aircraft crash immediately after the end of the period of institutional control. This risk value is comfortably below the risk target of 1×10^{-6}/yr.

E8.6.8 Climate Change

In interpreting the results for the transition to a wetter climate, it should be borne in mind that such a climate change will happen many hundreds or thousands of years after the period of institutional control ceases. It will be assumed that the climate change has been manifested, and a critical group established in the vicinity of the repository, 5000 years after repository closure.

At this time, the assessed effective dose rate to critical group members would be:

D(climate change, settler) = 4.6×10^{-5} Sv/yr
D(climate change, nomad) = 1.2×10^{-5} Sv/yr

The largest single contribution is made by ^{210}Po, and the most important exposure pathway is ingestion of meat (though ingestion of plant materials also provides a contribution of a similar order of magnitude).

The conditional risk is obtained by multiplying this dose by the dose-to-risk conversion factor of 0.06/Sv, leading to conditional risks of:

R(climate change, settler) = 2.8×10^{-6}/yr
R(climate change, nomad) = 7.1×10^{-7}/yr

It is important to note that this is the risk of cancer induction (or serious hereditary effects) that would occur if the climate change scenario definitely occurs. No attempt has been made to estimate the probability (or degree of belief) of occurrence of such climate change, as this requires more detailed information about the disposal site and its evolution in time.

It can be seen that, if the climate change scenario were definitely to occur, the conditional risk would be below a risk target of 1×10^{-6}/yr for nomads, but slightly above for settlers. However, the degree of belief associated with the occurrence of this scenario will be somewhat less than unity, and as such the individual risk is likely to be below the risk target.

E8.6.9 Gross Erosion

As in the interpretation of the results for the transition to a wetter climate, it should be borne in mind that gross erosional events will happen thousands of years after the period of institutional control ceases. It will be assumed that gross erosion has been manifested, and a critical group established in the vicinity of the repository, 5000 years after closure of the repository.

At this time, the assessed effective dose rate to critical group members would be:

D(erosion, settler) = 3.6 x 10^{-5} Sv/yr
D(erosion, nomad) = 4.9 x 10^{-6} Sv/yr

The largest single contribution for the settler doses is made by ^{210}Po, and the most important exposure pathway is ingestion of meat (though ingestion of plant materials also provides a contribution of similar magnitude). For nomads, ^{238}U provides the largest single contribution to dose.

The conditional risk is obtained by multiplying this dose by the dose-to-risk conversion factor of 0.06/Sv, leading to conditional risks of around:

R(erosion, settler) = 2.1 x 10^{-6}/yr
R(erosion, nomad) = 3.0 x 10^{-7}/yr

It is important to note that this is the risk of cancer induction (or serious hereditary effects) that would occur if gross erosion of the repository definitely occurs. No attempt has been made to estimate the probability (or degree of belief) of occurrence of such an event, as this requires more detailed information about the disposal site and its evolution in time.

It can be seen that, if the gross erosion scenario were definitely to occur, the conditional risk would be below a risk target of 1 x 10^{-6} /yr for nomads, but slightly above for settlers. However, the degree of belief associated with the occurrence of this scenario will be somewhat less than unity, and as such the individual risk is likely to be below the risk target.

E8.6.10 Site Flooding

As in the interpretation of the results for the transition to a wetter climate, it should be borne in mind that site flooding will happen thousands of years after the period of institutional control ceases. In addition, it will only occur in a wetter climate state. It will be assumed that site flooding has been manifested, and a critical group established in the vicinity of the repository, 5000 years after closure of the repository.

At this time, the assessed effective dose rate to critical group members would be:

D(flooding, settler) = 3.2 x 10^{-5} Sv/yr
D(flooding, nomad) = 8.3 x 10^{-6} Sv/yr

The largest single contribution is made by ^{210}Po, and the most important exposure pathway is ingestion of meat (though ingestion of plant materials also provides a contribution of similar magnitude).

The conditional risk is obtained by multiplying this dose by the dose-to-risk conversion factor of 0.06/Sv, leading to conditional risks of:

R(flooding, settler) = 1.9 x 10^{-6}/yr
R(flooding, nomad) = 5 x 10^{-7}/yr

It is important to note that this is the risk of cancer induction (or serious hereditary effects) that would occur if flooding of the repository site definitely occurs. No attempt has been made to estimate the probability (or degree of belief) of occurrence of such an event, as this requires more detailed information about the disposal site and its evolution in time, in particular the properties of natural drainage and any engineered drainage facilities at the site.

It can be seen that, if the site flooding scenario were definitely to occur, the conditional risk would be below a risk target of 1 x 10^{-6}/yr for nomads, but slightly above for settlers. However, the degree of belief associated with the occurrence of this scenario will be somewhat less than unity, and as such the individual risk is likely to be below the risk target.

E8.6.11 Consumption of Contaminated Waters

The consumption of well waters scenario only applies if the wetter climate state is manifested. Therefore, the results will be considered at a time of 5000 years after repository closure. At this time, the effective dose from water obtained from a well drilled at the repository site would be:

$$D(\text{drinking water}) = 2.8 \times 10^{-3} \text{ Sv/yr}$$

with ^{238}U being the main contributor (about half of the total).

Taking into account the dose-to-risk conversion factor of 0.06/Sv and the frequency of occurrence of well drilling on a farm of area 1 km^2, the annual individual risk is around:

$$R(\text{drinking water}) = 1.9 \times 10^{-7}\text{/yr}$$

for consumption of contaminated waters. This risk value is well below the risk target of 1×10^{-6}/yr.

An assessment of the effects of drinking water extracted from the regional aquifer underlying the repository is given in Section E8.9.

E8.6.12 Effects of Gas

The results obtained from the gas assessment are presented in Section E8.8.

E8.7 Doses Arising from Sources

In Sections E8.5 and E8.6, an assessment of radiological dose and risk was described and presented for the human intrusion and natural disruptive event scenarios, based on the assumption of homogeneous mixing of wastes through the total waste volume. This approach considerably simplifies the task of dose assessment, but it does not allow for the effects of localised sources of high activity in the wastes.

In this section, the doses arising from handling a number of sealed sources will be discussed. After an intrusion in the form of excavation of repository materials has taken place, it is likely that a considerable amount of repository material will lie in the accessible environment. This will include some or all of the sealed sources that have been disposed of in the repository. It is considered that such sources constitute items of interest, and may be picked up by members of the public walking close by, and who happen to see them lying on the ground. In order to investigate the effects of handling such sources, three characteristic sources have been identified from inventory to be disposed of at the proposed Australian repository (all assumed to be a cylinder of diameter 2 cm and length 5 cm):

- a 0.185 GBq source of ^{60}Co
- a 480 GBq source of ^{137}Cs
- a 0.37 GBq source of ^{226}Ra

The dose rate at the surface of such a cylinder is given by:

$$D = \frac{g\Gamma C}{2}$$

where D (Gy/hr) is the absorbed dose at the surface
Γ (Gy m^2/MBq hr) is the specific gamma ray emission

C (MBq/m^3) is the concentration in the cylinder
g (m) is a geometric factor.

For a cylinder of the dimensions above, *g* ~ 20 m, and Γ is of the order of 2.3 x 10^{-7} Gy m^2/MBq/h for ^{226}Ra, 8.7 x 10^{-7} Gy m^2/MBq/h for ^{137}Cs and 3.56e x 10^{-7} Gy m^2/MBq/h for ^{60}Co. The following dose rates to the hand are therefore obtained for a person holding these sources:

^{60}Co	Absorbed dose rate ~ 40 Gy/h
^{137}Cs	Absorbed dose rate ~ 25,000 Gy/h
^{226}Ra	Absorbed dose rate ~ 50 Gy/h.

For someone standing a short distance away from such a source (for example having taken the source home and placing it on a table or mantelpiece), the dose rate can be estimated from the following expression:

$$D = \frac{ME}{6r^2}$$

where D (uSv/hr) is the effective dose rate
M (MBq) is the amount of radionuclide in the source
E (MeV) is the gamma energy of the source
r (m) is the distance away from the source.

For a ^{226}Ra source similar to the one considered above, *E* is approximately 1 MeV (^{226}Ra and its daughters emit a large number of gamma rays at various energies: 1 MeV is an estimate of the mean gamma energy). For ^{137}Cs, *E* is 0.662 MeV, and for ^{60}Co, the combined photon energy per decay is 2.5 MeV.

For *r* = 1 m, the effective dose rates are:

^{60}Co	Effective dose rate ~ 0.08 mSv/h
^{137}Cs	Effective dose rate ~ 50 mSv/h
^{226}Ra	Effective dose rate ~ 0.06 mSv/h.

The doses arising from handling these sealed sources are considerable, in particular the dose arising from the high activity ^{137}Cs source. Holding such a source for more than about a few seconds would result in deep dermal necrosis and intense pain. Dermal burns would also result from holding the ^{60}Co and ^{226}Ra sources, but the exposure time required is much greater, probably in excess of one hour (though this could arise if the source is, for example, placed in a shirt pocket).

The doses arising from exposure to a sealed source at a distance of 1 m are much lower, but if exposure occurred for a day or more to the ^{137}Cs source, this could be sufficient to lead to the onset of acute whole-body effects, for example haemopoietic syndrome. However, experience has tended to show that dermal burns arising from holding such sources are the most likely outcome.

The breakage of a source and subsequent inhalation of dust and aerosols generated during the breakage could lead to large effective doses. Assuming that deterministic effects are observed after receiving an acute dose of 1 Sv, then it would be necessary to inhale 1/(3.9 10^8) ~ 2.5 x 10^7 Bq of ^{137}Cs (using the ICRP 72 (1996) dose-per-unit-intake factor for ^{137}Cs by inhalation). This is only 0.005% of the activity stored in the 480 GBq source considered above.

It is therefore clear that excavation of repository contents could lead to a situation where sealed sources are returned to the accessible environment, with severe consequences for members of the public who pick up and carry around such sources, or who break them and inhale the contents. It is therefore recommended that a thorough examination is made of the sources to be disposed, and if significant sources are found, then consideration should be given to the removal of these sources (if possible), and that they should be disposed of at a site more robust against the effects of excavations.

However, consideration should also be given to the extremely low probability that such sources are removed by members of the public. Such a probability can be estimated by considering that both an excavation event is required, and the presence of a community with a distance of (for example) 1 km of the repository site. That is, a population centre is required within an area of around 3 km^2, centred on the repository location.

In other calculations presented in this assessment, it has been estimated that the frequency of excavation events at the repository location is around 10^{-4} per year. Similarly, the probability of a community being located with a given area of 3 km^2 is $0.001 \times 3 = 0.003$. This latter calculation assumes 1 community per 1000 km^2, with the community size being much smaller than the target area. Thus, the probability of someone picking up such a source is approximately

$$P(\text{pick up source}) \sim 10^{-4} \times 3\ 10^{-3} \sim 10^{-7} \text{ per year.}$$

This is a very small estimated probability. It should also be noted that ^{60}Co has a half life of only 6 years, so if the integrity of the repository cap is sufficient, most of the ^{60}Co will have decayed away before an excavation intrusion can occur. It is arguable that the 30-year half-life of ^{137}Cs is also sufficiently low for this to be true.

E8.8 Assessment of Hazards Arising from Gas

A preliminary assessment of the radiological impact of the release of gases from the waste following the end of institutional control of the repository is reported in this section.

A brief explanation of the gas pathway is given first, in Section E8.8.1. Then, in Sections E8.8.2 to E8.8.5, the potential impact is assessed of the release of tritium (^3H), carbon-14 (^{14}C), krypton-85 (^{85}Kr) and radon (^{220}Rn and ^{222}Rn) in gaseous form from the wastes. The conclusions of the gas assessment are summarised in Section E8.8.6.

E8.8.1 Gas Pathway

A number of processes can lead to the generation of gas in a repository, including:

- corrosion of metals
- microbial action
- radiolysis.

The corrosion of steels can release hydrogen but this requires anaerobic conditions. Some more reactive metals sometimes found in radioactive wastes, such as aluminium and uranium, also corrode to release hydrogen. These metals do not require anaerobic conditions and can release hydrogen when corroding under aerobic conditions. Note that the metals must be in metallic form to corrode, i.e. they should not already be oxidised. Conditions are most likely to be oxidising in the national repository because it would be constructed in the unsaturated zone, and a substantial increase in soil and rock moisture is not likely to occur as a result of climate change in the next 10,000 years.

Microbial degradation of organic materials, particularly cellulose, can generate a number of gases, including mainly CO_2 and CH_4, but also H_2, H_2S and N_2. Radiolysis would also generate gas, but this process is unlikely to provide a significant source for the relatively low-activity wastes to be disposed of in the national repository. All these processes require the presence of water. If the gas generation rate were large enough, a flow of gas to the surface would be created.

Radionuclides could get incorporated into the ‘bulk’ gases generated by the processes just described to form trace quantities of radioactive gases. Any tritium in metals could be released by corrosion to form H^3H. $^{14}CO_2$ and $^{14}CH_4$ could be formed by microbial action on ^{14}C-containing wastes. Corrosion or microbial action in the presence of tritiated water could lead to the creation of H^3H or $CH_3{}^3H$. Tritiated water might also evaporate. Radioactive gases could also be released directly from wastes. Tritium or

^{85}Kr might leak or diffuse out of materials, for example. Radioactive decay of uranium, thorium and radium leads to the formation of radon which is gaseous.

The radioactive gases might diffuse out of the repository towards the ground surface if there were already a gas path, as would be expected at the national repository, or be carried in a flow of bulk gases upwards if there were such a flow. A flow of bulk gas might also increase the impact of the creation of radon by the decay of uranium and thorium which will be present naturally to some extent in the soil. This might occur if the bulk gas carried the radon more quickly to the surface, allowing less time for radioactive decay of the radon within the soil.

There are two main ways in which radioactive gases might have a detrimental impact. The activity in the hydrogen, carbon dioxide and methane might be incorporated into the soil by microbial action and enter a foodchain (though this might require wetter conditions than those currently in existence at the proposed site). Alternatively, any of the radioactive gases might be released from the ground surface and give a dose by external irradiation or inhalation. The latter impacts would only likely be significant if the gases were released into an occupied confined space, such as a house.

The generation of bulk gases from a repository might lead to non-radiological hazards, including the release of toxic, asphyxiating or flammable gases.

E8.8.2 Tritium

The initial inventory of ^{3}H is estimated to be 1.6 x 10^{12} Bq (see Table E8.1). ^{3}H has a relatively short half-life of 12.4 years, compared with many radionuclides of interest in repository safety studies, and would decay away over a period of a few hundred years.

The ^{3}H is mostly in the form of gaseous light sources in the existing inventory of wastes. Assuming ^{3}H would be disposed of in this form, it is difficult to predict with any certainty whether the ^{3}H would be released from the sources and the rate at which this might occur. For the ^{3}H to be released by diffusion out of the sources in the post-closure phase, the diffusion rate would have to be relatively slow, otherwise the tritium would already have diffused out of the wastes before closure of the repository.

The ^{3}H could be released if the sources broke after repository closure because of, for example, corrosion of metal fittings or the wasteforms evolving. The release of any ^{3}H contained in or by metals would be limited by diffusion or corrosion rates. It might be expected that corrosion and other waste package degradation mechanisms would be slow in the relatively dry ground of the region and there would be limited changes to of the waste packages, at least over the period the ^{3}H would exist in any significant quantity.

If ^{3}H were released from the wastes after repository closure, a significant impact would still not be expected. In the case of ^{3}H released out of the ground, this is because of the short half-life of ^{3}H compared with the assumed 200-year period of institutional control. After 200 years, the inventory of tritium (assuming no earlier release) would have decayed to 2.2 10^{7} Bq. Only after the end of the period of institutional control should there be a possibility of buildings being constructed over the repository.

The radiological dose from inhalation and skin uptake resulting from the release of a quantity I (Bq) of gaseous activity from a repository of area A (m^2) into a building room height h (m) is given by:

$$H_{Gas} = \frac{\phi B H_2 I}{\lambda_V h A} \qquad (8.1)$$

where ϕ (-) Enhancement factor to allow for uptake by skin
B (m^3/yr) breathing rate
H_2 (Sv/Bq) is the committed effective dose per unit uptake by inhalation
λ_V (yr) ventilation rate of the room.

This equation cautiously assumes that an individual occupies the building all the time. The equation also assumes that the gas released into the building would be the fraction of the total released from the repository given by multiplying the total by the area of the building divided by the area of the repository, that is, it assumes a uniform release of gas over the area of the repository and that gas is not preferentially drawn into or excluded from the building. A large fraction of the gas might be excluded if the building were constructed on a layer of concrete foundation.

If the gas were released from the repository non-uniformly, the radiological dose would be higher if the building stood over an area of relatively high release, but the likelihood of the dose being received would be correspondingly lower. The equation also assumes that the losses of the gas from the building will be dominated by the ventilation and not deposition, if this were to occur, and radioactive decay. Ventilation rates in buildings are typically about one air change per hour and, therefore, losses by ventilation would dominate over losses through decay of ^3H (and ^{14}C, ^{85}Kr and ^{222}Rn).

Using Equation 8.1, the radiological dose from the release from the ground of all the remaining ^3H after 200 years (2.2 x 10^7 Bq) over one year, with some fraction of it entering an occupied building, can be calculated to be 2 x 10^{-4} mSv. This dose is low compared with the effective dose limit of 1 mSv/yr (Section 3.1). Along with the assumption of all the remaining ^3H being released within one year, the calculation also cautiously assumes that a building would be built on the repository just after the end of the period of institutional control. The assumptions made about parameter values are set out below.

A range of soil microbes are capable of oxidising hydrogen to water. H^3HO is also much more radiotoxic than H^3H. It was cautiously assumed for the above dose calculation that the ^3H remaining after decay would be released above ground in the form of H^3HO vapour. The value of H_2 was taken to be 1.8 x 10^{-11} Sv/Bq (International Commission on Radiological Protection 1996). A value of 1.5 for the skin uptake factor, ϕ, is appropriate for ^3H in the form of water (International Commission on Radiological Protection 1979). The breathing rate was assumed to be 6900 m^3/yr, a value for a reasonable mix of activities (Baker et al. 1997). The area of the repository, *A*, was taken to be 1000 m^2. This is the estimated area of the structures to be used for waste disposal and excludes, for example, any area between different disposal structures. Typical values were used for room height, *h*, of 2.5 m, and ventilation rate, λ_V, of 8800/yr (1/h).

The effective dose calculated above is conditional on a house being constructed above the repository. The associated risk would be very low. A simple estimate of the probability that a house would be constructed over the repository can be obtained by dividing the current population of the Woomera Protected Area (3500; JA Ryan, GHD, pers. comm. Feb 2002) by its area (127,000 km^2 JA Ryan, GHD, pers. comm. Feb 2002), assuming a house would be occupied by a small number of people, and taking account of the footprint of the waste trench (1000 m^2). The population of 3500 includes that of the towns Coober Pedy and Glendambo which are not in the WPA, but are surrounded by it. The calculation gives a probability of 10^{-5} that a house would be constructed over the repository. This suggests the risk from the release of the ^3H out of the ground would be less than 10^{-13}/yr. This risk is very small compared with the risk limit of 1 10^{-6}/yr.

It has been assumed in the analysis above that the ^3H would be released from the ground in gaseous form. If the ^3H remained in the soil, no significant radiological impact would be expected to occur under present conditions. For a significant impact to occur, the contaminated soil would have to be used for relatively intensive farming or the soil water used as a source for drinking water for humans or farm animals. The change in climate this would require is unlikely to occur on the timescales that significant quantities of ^3H would remain. Although the conditional dose that would be calculated for this pathway might be higher than for the release of gas above ground, the amount of ^3H left after 200 years, at the end of the period of institutional control, would still be too low for the dose to be significant relative to the dose limit of 1 mSv/yr.

E8.8.3 Carbon-14

The initial inventory of ^{14}C is estimated to be 9.7 x 10^5 Bq (see Table E8.1). The half-life of ^{14}C, at 5730 years, is much longer than that of ^3H. It follows that the fractional decrease in inventory over the 200-year period of institutional control, of about 2.5%, would be much lower for ^{14}C than for ^3H. The initial inventory of ^{14}C, however, is estimated to be much lower than that of the ^{3}H. Even after 200 years the inventory of ^{14}C, of 9.5×10^{5} Bq, would be an order of magnitude less than that of ^{3}H.

It is doubtful that the ^{14}C could be released in gaseous form from the wastes because of the type of the wastes containing the ^{14}C. In the current inventory, the ^{14}C is described as being in the form of sealed or calibration sources. The ^{14}C would not therefore be expected to be in biologically available, for example organic, form which could be acted on by microbes to release $^{14}CO_2$ or $^{14}CH_4$.

If, however, it is assumed that the ^{14}C would be released in gaseous form above the ground, Equation 8.1 can be used to calculate the resulting radiological dose, assuming that a building is constructed and occupied above the repository. Here it is assumed that the ^{14}C would be released in the form of $^{14}CO_2$. $^{14}CH_4$ released into the soil at least to some extent would be expected to be metabolised by microbes to $^{14}CO_2$. $^{14}CO_2$ is also more radiotoxic than $^{14}CH_4$. The appropriate value for H_2 is 6.2×10^{-12} Sv/Bq (International Commission on Radiological Protection 1996). In the case of $^{14}CO_2$, the skin uptake factor, ϕ, should be set to one. If it assumed that the ^{14}C inventory remaining after 200 years is released within one year, and using the same values for the parameters B, λ_v, h and A as before, an effective dose of 2×10^{-6} mSv. Again, this dose is very low compared with the dose limit of 1 mSv/yr. The corresponding risk would also again be very small compared with the risk limit of 1×10^{-6}/yr.

If the ^{14}C were released from the wastes but remained in the soil, as with the ^{3}H, no significant radiological impact would be expected to occur under present conditions. Although the ^{14}C has a longer half-life than ^{3}H and might still exist on timescales when significant changes in climate and land use might occur, its small initial inventory means that any impact is unlikely to be significant.

E8.8.4 Krypton-85

The initial inventory of ^{85}Kr is estimated to be 7.0×10^{9} Bq. ^{85}Kr has a short half-life of 10.7 years, similar to that of ^{3}H. After the institutional control period of 200 years, the inventory of ^{85}Kr would have reduced to the low value of 1.7×10^{4} Bq. Any release of the ^{85}Kr after closure would be expected to be slow, for similar reasons to that for the ^{3}H.

Using Equation 8.1 and making the same assumptions as before, the effective dose to occupants of a building over the repository resulting from the release in one year of all the ^{85}Kr remaining after 200 years was calculated to be 3×10^{-9} mSv. For this calculation, the skin uptake factor, ϕ, was set to one and BH_2 was taken to be 4.2×10^{-9} Sv/yr per Bq/m^{3} (International Commission on Radiological Protection 1994a). Again, the calculated dose and associated risk are very small.

E8.8.5 Radon

The case of radon is different from the other radioactive gases considered above in two important respects: the two radon isotopes ^{220}Rn and ^{222}Rn have very short half-lives compared with the other radioactive gases, but they will be continuously be created by the decay of radium. The initial inventory would contain radium and radium would also be produced by the decay of its precursor thorium and uranium isotopes in the inventory.

The half-lives of ^{220}Rn and ^{222}Rn are 56 s and 3.8 d respectively. These half-lives are short enough for containment in the wastes, waste packaging and soil to cause significant decay of the radon produced. In the case of the ^{220}Rn, its half-life is so short that none would be likely to be released above ground. Assuming a 5 m layer of soil above the wastes and an effective diffusion coefficient for dry soil of 10^{-6} m^{2}/s (a typical value for dry soil), the timescale for diffusion through the layer would be about three months, allowing time for all of the ^{220}Rn, and a large proportion of the ^{222}Rn, to decay. Of course, if the cap erodes away in time, there is potential for greater amount of ^{222}Rn to reach the ground surface.

This conclusion that there would be significant decay of radon assumes that there would not be a flow of bulk gases from the repository up through the soil that would carry the radon to the surface significantly more quickly than by diffusion. The creation of bulk gases in the national repository should be limited by its location in the unsaturated zone in an arid area. Also, much of the uranium is expected to be already in oxidised form and, in any case, the quantity of uranium in the inventory would not be large enough to cause a significant bulk flow of gas. If bathtubbing occurred for an extended period, however, gas generation from anaerobic corrosion of steels would occur to some extent. A detailed calculation of bulk gas generation rates is beyond the scope of this assessment.

In contrast to ^{3}H, ^{14}C and ^{85}Kr, the quantity of ^{222}Rn that is produced and released from the repository could be considerable, owing to the substantial inventories of ^{238}U and ^{226}Ra present in the repository. In addition, the radioactive daughters of ^{222}Rn are more radiotoxic than gases labelled with ^{3}H and ^{14}C, as they are alpha emitters, so it might be expected that effective doses from inhaling ^{222}Rn will be greater than the other radionuclides considered so far.

In order to estimate the doses arising from ^{222}Rn emerging from the ground surface and entering a house built on the repository, consider the schematic layout of the repository shown in Figure E8.20. It is assumed that the ^{226}Ra and ^{238}U present in the disposed wastes are distributed uniformly through the total volume of the wastes. Under this assumption, the fraction of the inventory stored in the 'slice' d*x* will diffuse through a distance *x* before reaching the ground surface. The time required to diffuse this distance is, approximately:

$$T = \frac{x^2}{4D} \qquad (8.2)$$

where *D* is the diffusion coefficient for radon through the overlying materials. Of course, the overlying materials will be composed of a number of different substances, including concrete, soils and waste packaging. However, a suitably cautious assumption is to assume that the overlying materials are predominantly soils, so that the diffusion coefficient has a value of around 10^{-6} m^2/s.

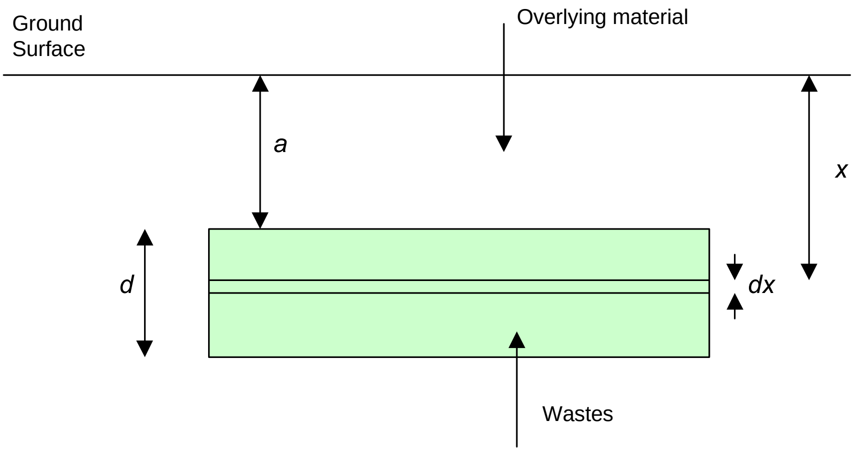

FIGURE E8.20
Schematic system for estimating radon release rates

Therefore, the activity flux (in Bq/yr) emerging from the ground surface from the element d*x*, assuming that all of the radon produced by decay is channelled upwards, is:

$$\delta F = \frac{\lambda I}{d} \exp(-\frac{\lambda x^2}{4D}) dx \qquad (8.3)$$

where λ is the decay constant for ^{222}Rn (this is required as activity units are being employed for the radionuclide inventories, rather than mass units). Integrating over the depth of the repository leads to:

$$F = \frac{\lambda I}{d} \left(\frac{4D}{\lambda} \right)^{1/2} \int_{a(\lambda/4D)^{1/2}}^{(a+d)(\lambda/4D)^{1/2}} \exp(-z^2) dz \qquad (8.4)$$

Which can be evaluated in terms of the error function, erf(x), to give:

$$F = \frac{I(\pi\lambda D)^{1/2}}{d}\left[\operatorname{erf}\left((a+d)\left(\frac{\lambda}{4D}\right)^{1/2}\right) - \operatorname{erf}\left(a\left(\frac{\lambda}{4D}\right)^{1/2}\right)\right] \quad (8.5)$$

The most recent publication dealing with radon and the associated health effects is ICRP 65 (1994b). Taking into account the comments in ICRP Publication 65, the exposure of members of the public to radon is given by:

$$E_{\mathrm{Rn}} = 1.1 P_p \quad (8.6)$$

where E_{Rn} (Sv/yr) is the annual effective dose due to exposure to radon progeny;
P_p (J hr/m^3/yr) is the potential alpha energy exposure per year.

Overall, it may be shown that

$$P_p = 5.56\ 10^{-9} C_{\mathrm{Rn}} T_{\mathrm{Rn}} \quad (8.7)$$

where T_{Rn} (hr/yr) is the annual period of ^{222}Rn exposure.

The concentration of radon in the room of a house built on top of the repository, and suffering a constant influx F of radon, is given by

$$C_{\mathrm{Rn}} = \frac{F}{\lambda_V h A} \quad (8.8)$$

where F is as given in Equation 8.4, and the other symbols are as defined in Equation 8.1. Losses from the room by radioactive decay have been neglected in this expression.

A key input to the calculation of radon fluxes is the inventory of ^{226}Ra and its variation over time. This is shown in Figure E8.21. The graph shows two distinct regimes. At early times, the inventory is governed by the decay of ^{226}Ra that was present at repository closure, whereas at later times, it is governed by ingrowth from the decay of ^{238}U. At times less than 10^4 years after closure, the maximum inventory is 8.25 x 10^{10} Bq. After an institutional period of control, it has fallen to 7.5 x 10^{10} Bq. After 5000 years (the time period over which the cap might be expected to erode away in the worst case erosion scenario, and which has been assumed in other scenarios considered in this report — see Section 4.9), the inventory of ^{226}Ra has dropped to around 1 x 10^{10} Bq. The results are shown in Table E8.33, for ^{226}Ra inventories just after institutional control ends, and at 5000 years after closure.

With the cap still intact and 5 m thick, it can be seen that radiation doses would be negligible.

However, when the cap has eroded away, effective doses to home occupiers can be significant — as much as 130 mSv/yr for the base case diffusion coefficient of 10^{-6} m^2/s. However, it can also be seen that if materials of a lower diffusivity are used (e.g. concrete, which has a diffusion coefficient of around 10^{-8} m^2/sec), then doses drop to insignificant levels, even if the cap is completely eroded away. In terms of radiological risk, 130 mSv/yr equates to an individual risk of:

$$0.13 \times 0.06 \times 10^{-5} = 7.8 \times 10^{-8}\text{/yr.}$$

This is substantially lower than the recommended risk target of 1 x 10^{-6}/yr.

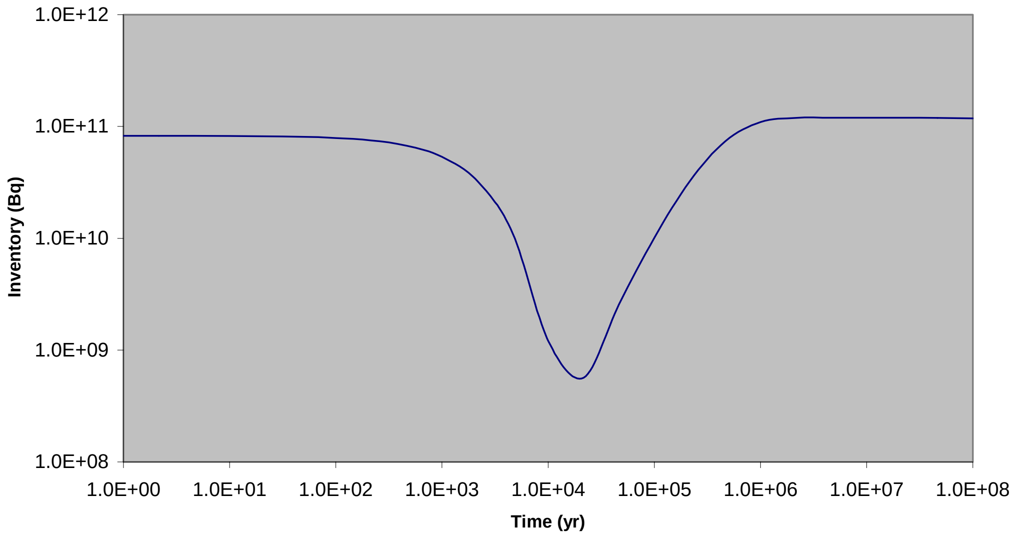

FIGURE E8.21
Inventory of ^{226}Ra as a function of time

E8.8.6 Conclusions

The annual effective doses from the release of radioactive gases from the national repository have been calculated using a number of conservative assumptions to be (mSv):

^{3}H	2×10^{-4}
^{14}C	2×10^{-6}
^{85}Kr	3×10^{-9}
^{220}Rn	0
^{222}Rn	up to 130

With the exception of ^{222}Rn, these calculated annual doses are all less than the dose limit of 1 mSv/yr. For the first four radionuclides, the calculated annual doses are very much smaller.

For the ^{3}H, ^{14}C and ^{85}Kr, it was cautiously assumed for the calculations that the inventories of the radionuclides remaining at the end of the 200-year period of institutional control would be released over a period of one year after there being no release before, and a continuously occupied building would be above the repository. In the case of the ^{14}C it is possible that none would be released in gaseous form because it would not be in a biologically available form in the wastes.

The release of the ^{3}H and ^{85}Kr would not be expected to occur in one particular year at the end of the period of institutional control. If the ^{3}H or ^{14}C were released from the wastes and incorporated in the soil, as might occur, there would no significant impact under current conditions. The ^{3}H would be expected to decay away before any change occurred in climate great enough for an impact. Although the ^{14}C would last longer, its initial inventory would too small to have a significant impact if present in the soil.

A simple estimate of the likelihood of a house being constructed over the repository, based on the area and current population of the WPA, suggests the probability would be about 10^{-5}. On this basis, the risks associated with the release of the radioactive gases from the repository would be very small compared with the risk limit of 1×10^{-6}/yr.

The effective dose rate from ^{222}Rn and its progeny, in the worst case assumption of no covering materials and a house built on top of the facility, is around 130 mSv/yr. In risk terms, this equates to an individual risk of around 8×10^{-8}/yr, when the probability of building a house on top of the repository is taken into account. The calculation also showed that the use of backfilling materials of low diffusivity would reduce radon doses considerably, even if the cap ceases to be present at some stage in the future (see Section E8.4.9).

TABLE E8.33 Radon doses (Sv/yr) as a function of diffusion coefficient and cap thickness

1. After institutional control ceases

Diffusion coefficient (m^2/sec)	Cap thickness (m)										
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
3.00E-05	5.10E+00	4.76E+00	4.41E+00	4.06E+00	3.71E+00	3.37E+00	3.04E+00	2.72E+00	2.42E+00	2.14E+00	1.87E+00
1.00E-05	3.13E+00	2.73E+00	2.34E+00	1.97E+00	1.62E+00	1.31E+00	1.04E+00	8.05E-01	6.11E-01	4.54E-01	3.30E-01
3.00E-06	1.72E+00	1.32E+00	9.52E-01	6.44E-01	4.07E-01	2.39E-01	1.30E-01	6.59E-02	3.08E-02	1.33E-02	5.32E-03
1.00E-06	9.92E-01	6.03E-01	3.03E-01	1.23E-01	4.01E-02	1.03E-02	2.09E-03	3.32E-04	4.12E-05	3.97E-06	2.97E-07
3.00E-07	5.43E-01	1.90E-01	3.33E-02	2.72E-03	9.93E-05	1.58E-06	1.08E-08	3.17E-11	3.94E-14	0.00E+00	0.00E+00
1.00E-07	3.14E-01	3.30E-02	3.74E-04	3.67E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

2. After 5000 years post-closure

Diffusion coefficient (m^2/sec)	Cap thickness (m)										
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
3.00E-05	6.80E-01	6.34E-01	5.88E-01	5.41E-01	4.95E-01	4.49E-01	4.05E-01	3.63E-01	3.23E-01	2.85E-01	2.50E-01
1.00E-05	4.18E-01	3.64E-01	3.12E-01	2.62E-01	2.16E-01	1.75E-01	1.38E-01	1.07E-01	8.15E-02	6.05E-02	4.40E-02
3.00E-06	2.29E-01	1.76E-01	1.27E-01	8.58E-02	5.42E-02	3.19E-02	1.74E-02	8.79E-03	4.11E-03	1.78E-03	7.09E-04
1.00E-06	1.32E-01	8.04E-02	4.04E-02	1.64E-02	5.34E-03	1.38E-03	2.79E-04	4.43E-05	5.49E-06	5.30E-07	3.97E-08
3.00E-07	7.24E-02	2.53E-02	4.44E-03	3.63E-04	1.32E-05	2.11E-07	1.44E-09	4.23E-12	5.25E-15	0.00E+00	0.00E+00
1.00E-07	4.18E-02	4.40E-03	4.99E-05	4.89E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

An engineered, multi-layer cap of 5 m thickness and suitable backfill material would mitigate the effects of ^{222}Rn emanation from the repository. However, this conclusion is contingent on the cap not acquiring fissures or cracks that might provide a preferential leakage pathway out of the repository.

The impact of non-radiological hazards from the release of bulk gases has not been assessed. There are, however, reasons for believing that the release of bulk gases from the national repository in its proposed location would be low.

E8.9 Groundwater Leaching through Unsaturated Zone

A preliminary assessment of the radiological impact of the release of radionuclides into groundwater from the waste following closure of the repository is reported in this section.

A brief explanation of the groundwater pathway is given first, in Section E8.9.1. An analysis is then made in Sections E8.9.2 and E8.9.3 of the impact from the pathway for the national repository. The conclusions of the groundwater pathway assessment are summarised in Section E8.9.3.

The calculation reported in this section relates to effects on groundwater in the aquifer underlying the repository. An assessment of doses arising from water abstraction and consumption from the repository itself is described in Section E8.4.11.

E8.9.1 Groundwater Pathway

If groundwater gained access to radioactive waste disposed in a repository, radionuclides might dissolve into the groundwater. The radionuclides would then be able to diffuse out of the repository or be carried out in the groundwater if it was flowing through the repository. The radioactivity in the groundwater might then lead to a radiological impact. An adverse impact might result if the contaminated groundwater entered soil or an open waterbody and hence a foodchain. Contaminated groundwater might also be drawn from wells for drinking water for humans or farm animals, or for irrigation.

The release of radionuclides from a repository in groundwater can be limited by a number of factors. The solubility of radioelements may be limited under the chemical conditions in a repository. This would mean that only a limited quantity of a radioisotope of such an element could leak out over a time period, assuming there were sufficient quantity of the radioelement to reach its solubility limit. Sorption on to repository materials of radioisotopes of non-solubility limited radioelements would slow their release. Dissolution or corrosion rates of wastes might limit the rate of release of radionuclides.

There might also be physical, rather than chemical, barriers to the release of radionuclides. Groundwater might take some time to flow into a repository after closure. If the repository was not fully saturated, not all the wastes might be in contact with water and hence able to release radionuclides. Waste containers might need to corrode first before groundwater could gain access to the wastes. Diffusion rates of radionuclides through repository materials might significantly slow their release. The volume flux of groundwater flowing through the repository would affect the quantity of solubility limited radionuclides that could flow out over a period. A slower rate of release of radionuclides would allow time for decay and also limit the concentrations of radionuclides in groundwater.

Once radionuclides were released from a repository, a number of processes would cause dilution and allow time for further decay before the radionuclides could reach soil, a waterbody or a well. Radionuclides would take some time to reach the ground surface because of finite groundwater flow rates or diffusion rates of radionuclides through groundwater. Sorption of radionuclides on to rocks would significantly slow the transport of many radionuclides. Dispersion and diffusion would tend to reduce the concentrations of radionuclides in groundwater; although dispersion under some circumstances could mean radionuclides reaching an outlet earlier than would be expected from the average velocity of the groundwater, hence allowing less time for decay.

E8.9.2 Analysis of Groundwater Pathway

The proposed location for the national repository is in the unsaturated zone in an arid region. The quantity of water in the unsaturated zone would in general be low. Design measures might also be taken to limit the infiltration rate of rainwater through the repository. These and at least some of the other factors mentioned in the previous subsection would limit the release of radionuclides from the repository. It will be assumed here, however, that some at least of the radionuclides in the inventory would be released from the repository.

Radionuclides released from the repository would be expected to be carried down in the infiltrating groundwater through the unsaturated zone towards the aquifer below. Diffusion and dispersion would spread the release and sorption on to the rocks would be expected to slow the progress of most of the radionuclides. Any activity reaching the aquifer would mix with the infiltrating water into the aquifer water and be carried towards the outlet. Again, diffusion, dispersion and sorption would occur with similar effects.

Residence times for water in the unsaturated zone at the proposed repository location are estimated to be very long, at some tens of thousands of years (Bureau of Rural Sciences 2001). Assuming a residence time of 10^4 years, the time for different radioelements to reach the aquifer below the repository can be estimated, taking into account sorption on to the rocks. The travel time for a radioelement in the unsaturated zone is given by multiplying the residence time by the retardation coefficient, R, for the radioelement. The retardation coefficient is given by:

$$R = 1 + \frac{\rho k_d(\theta)}{n\theta} = 1 + \frac{\rho k_d}{n} \quad (9.1)$$

where it is assumed that:

$$k_d(\theta) = k_d \theta \quad (9.2)$$

where ρ (kg/m^3) is the density of the rock
n (-) is the porosity of the rock
θ (-) is the saturation
$k_d(\theta)$ (m^3/kg) is the radioelement distribution coefficient for a saturation θ
k_d (m^3/kg) is the radioelement distribution coefficient for saturated rock.

The estimated travel times for radionuclides with half-lives greater than 100 years in the initial inventory (see Table E8.1) are given in Table E8.34, along with the distribution coefficients assumed. Shorter-lived radionuclides will decay away in the unsaturated zone, whether or not they sorb on the rocks, if the residence time of the infiltrating water is of the order of 10^4 years.

TABLE E8.34 Estimated travel times for radionuclides with half-lives >100 years

Radio-element	Distribution coefficient for saturated rock (m^3/kg)	Estimated travel time (yr)
Am	3.2	7×10^8
C	7.1×10^{-3}	2×10^6
Ho	3.2	7×10^8
I	1.0×10^{-6}	1×10^4
Np	2.0×10^{-2}	5×10^6
Ra	2.0×10^{-1}	5×10^7
Th	3.5×10^{-1}	8×10^7
U	3.2×10^{-2}	7×10^6

The distribution coefficients used are best estimate values for hard rock and sandstone taken from reference (Bailey et al. 2000), with the exception of that for Ho, which was set equal to that for Am, on the basis of chemical analogy. Typical values for rock density and porosity were assumed, of 2250 kg/m^3 and 0.1 respectively.

The above results suggest that all the radionuclides, with the exception of ^{129}I, which would be expected to suffer little or no sorption, would either take more than a million years to reach the aquifer or decay away before reaching the aquifer.

It should be noted that the groundwater travel times through the unsaturated zone are based on chloride mass balance arguments. To apply these arguments, it is necessary to know the average chloride concentration in atmospheric precipitation (both oceanic and terrestrial contributions), average annual rainfall and the chloride concentration of groundwater at the watertable. In interpreting the return times given in Bailey et al. (2000), it should be borne in mind that this approach assumes that evaporated rainwater is the sole source of chloride in groundwater.

An additional factor should be noted when interpreting groundwater travel times obtained from chloride mass-balance considerations. The calculations are based on average rainfall obtained over an area somewhat larger than the repository footprint, and therefore the travel times presented are averages over this larger area. It is likely that there will be considerable smaller-scale variability in travel times, in particular, the travel times might be lower at the site of the proposed repository. Note that increased levels of rainfall (as would arise in a wetter climate state) will result in lower travel times through the unsaturated zone.

For a formal assessment that provides part of the input for regulatory approval to build the proposed repository, and which relies on long travel times as part of the safety argument, consideration should be given to obtaining additional evidence for such long travel times.

Distribution coefficients have been measured for two radioelements on rock samples taken from the proposed location of the national repository (Bureau of Rural Sciences 2001). Distribution coefficients were measured for Co and Cs. An estimated distribution coefficient for Cs is given in Bailey et al. (2000), allowing a comparison to be made. The average of the measured values for trace Cs in 0.5 M NaCl solution reported in Bailey et al. (2000) for samples from the proposed site is 0.5 m^3/kg. NaCl solution was chosen because of the saline nature of the groundwater.

Measured values for distribution coefficients for trace Cs in saturated $CaSO_4$ were higher (showing more sorption). $CaSO_4$ was also used because gypsum is abundant in many of the rocks. High concentrations of Cs in NaCl gave smaller distribution coefficients, but these data should be less relevant. The smaller values for distribution coefficients measured at high Cs concentrations may indicate sorption site saturation in the experiments. The best estimate value for Cs in Bailey et al. (2000) is 0.2 m^3/kg. The closeness of the 0.2 and 0.5 m^3/kg values for Cs provides some support for the use of the data from Bailey et al. (2000) for other radionuclides.

The results given above for estimated travel times to the aquifer suggest that only ^{129}I might reach the aquifer on less than a million-year timescale under current conditions. Even if the iodine did reach the aquifer under current conditions, no impact would be expected. The aquifer water is very saline and would not be expected to be consumed. Also, the inventory of ^{129}I is small, at 2 x 10^6 Bq, (Table E8.1) and would not cause high activity concentrations in the aquifer.

To illustrate this, consider the following. Assume the groundwater were potable and a well extracted water in the vicinity of the repository. If all the initial inventory of ^{129}I mixed in a short period with water in the aquifer below the repository and someone used this as their sole source of water, the dose they would receive would still be less than 1 mSv/yr.

This estimate is based on the following assumptions: the porosity of the rocks is 0.1, the area of the waste disposal structures would be 1000 m^2, the well would extract water from at least a few metres depth in the aquifer, a person would consume 1 m^3 of water in a year, and the dose factor for the consumption of ^{129}I is 1.1 x 10^{-7} Sv/Bq (Table E8.6). Thus, the ^{129}I would be diluted into around 500 m^3 of water, leading to a concentration of around 4000 Bq/m^3. Were the ^{129}I to be transported through the aquifer to the outlet, some 100 km away (Bailey et al. 2000), its concentration at the outlet would be lower than given above because of diffusion and dispersion.

E8.9.3 Consideration of the Uranium-238 Chain

An alternative method for evaluating the likely consequences of radionuclides reaching the aquifer is to compare contamination levels that might arise from repository derived radionuclides with naturally occurring levels. This is particularly appropriate for ^{238}U and its progeny, as naturally occurring levels of ^{238}U are readily available (or are easily obtained).

The potential impact of ^{238}U and its daughters reaching the aquifer can be obtained from the following very simple dilution argument. In the repository, the maximum concentration of ^{238}U in porewater will be defined by the solubility limit of uranium. In a high pH environment (though the precise pH that would be expected in the proposed facility is of course unknown at this stage), a typical value could be of order 10^{-3} mol/m^3 (Bailey et al. 2000). In terms of activity concentrations, this is equivalent to:

$$\ln(2) / (4.47\ 10^{9} \times 3.16\ 10^{7}) \times 6.02\ 10^{23} \times 10^{-3} \ \sim\ 3000\ \text{Bq/m}^3 \ =\ 3\ \text{Bq/L}$$

Available analyses (three samples) of groundwater indicate that ^{210}Pb is present in porewater in the general area of the repository at concentrations of between 0.2 and 0.8 Bq/L (RWE Nukem 2001), and ^{226}Ra is present at levels up to 0.2 Bq/L (these two isotopes are considered as they are, along with ^{210}Po, the most radiotoxic members of the ^{238}U chain). Assuming that secular equilibrium has been reached as ^{238}U in repository porewater makes its way through the unsaturated zone, it follows that a dilution factor of between 4 and 15 is required, to ensure that ^{210}Pb levels derived from the repository do not exceed natural levels in porewater. This requires that the flow rate in the aquifer (in m^3/sec, say) should exceed the flow rate from the unsaturated zone to the aquifer by a factor of 4 to 15. Bearing in mind the extremely low recharge levels in the unsaturated zone, this level of dilution should be achieved with ease.

It might be useful to obtain a wider range of water sample analyses, to provide a better view of the range of concentrations in local groundwaters. In addition, it might be useful to obtain ^{230}Th and U isotope concentrations, for more direct comparisons with the uranium concentration in the repository of 3 Bq/L.

E8.9.4 Conclusions

It is concluded that, under current conditions, there would be no significant impact from release of radionuclides into the groundwater. Were radionuclides released from the repository into the groundwater, the very small infiltration rate and hence long residence time of water in the unsaturated zone, coupled with the effect of sorption on the rocks, means that no radionuclide other than ^{129}I would be expected reach the aquifer below the repository within more than one million years. Even if the ^{129}I did reach the aquifer, no impact would be expected because of the saline nature of the groundwater and the low inventory of the ^{129}I.

This conclusion applies to current conditions and depends strongly on the assumption of long residence times in the unsaturated zone, based on the results and interpretation reported in Bailey et al. (2000). In particular, if rainfall rates were to increase, then residence times would be expected to decrease.

The chloride mass-balance technique that was used to estimate residence times depends on the assumption that only evaporated rainfall is solely responsible for chloride concentrations in groundwater. In addition, the intrinsic variability of rainfall could result in lower travel times at the repository site, compared with the regional average that is presented here.

E8.10 Summary and Discussion

In this section, the results of the dose and risk assessments are summarised, conclusions are drawn and recommendations for future assessment studies are presented.

A summary of the maximum doses and risks are presented for the human intrusion and natural event scenarios in Table E8.35.

TABLE E8.35 Summary of peak doses and risks for the human intrusion and natural disruptive event scenarios

Scenario	Critical group	Peak dose(1)	Peak risk(2)	Time (yr)(3)	Key nuclide
Borehole drillers	Geotechnical workers	1.7E-06	1.0E-11	200	Am-241
Bulk excavation	Excavation gang	3.5E-05	2.1E-10	200	Am-241
Road builders	Road building gang	9.6E-05	1.2E-10	200	Am-241
Archaeologists	Group of archaeologists	1.8E-03	1.1E-08	200	Am-241
Longer term exposures	Settlers who use excavated materials in gardens	1.5E-03	8.9E-08	200	Ra-226
Rocket crash	Settler children playing at site	9.6E-04	1.4E-09	200	Am-241
Aircraft crash	Aircraft recovery team	6.9E-05	2.9E-13	200	Am-241
Wetter climate	Subsistence/farming community	4.6E-05	2.8E-06	5000	Po-210
Gross erosion	Subsistence/farming community	3.6E-05	2.1E-06	5000	U-238
Site flooding (bathtubbing)	Subsistence/farming community	3.2E-05	1.9E-06	5000	Po-210
Contaminated well waters	Subsistence/farming community	3.1E-03	1.9E-07	5000	U-238

(1) Doses are effective doses, with units of Sv or Sv/yr.
(2) Risks are individual annual risks.
(3) Times are measured in years post-closure.

E8.10.1 Human Intrusion Scenarios

The human intrusion scenarios are the:

- effects of drilling and examination of borehole cores
- effects of bulk excavation of contaminated materials
- effects of building a road that runs across the repository
- effects of archaeological digging at the site
- longer-term effects arising from exposure to excavated materials
- effects of a rocket crash from the nearby Woomera test site
- effects of an aircraft crash onto the repository site
- effects of consuming contaminated waters obtained from a well drilled through the wastes.

The critical groups assumed for these scenarios are either outside workers, or settlers and nomads, depending on the timescale over which the scenario is active.

In general, assessed radiological doses are around or less than the public dose limit of 1 mSv/yr, and are an order of magnitude or more smaller than the ICRP 81 (1998) recommended level for intervention of 10 mSv/yr. Radiological risks are (in general) several orders of magnitude smaller than the recommended risk limit of 1 x 10^{-6}/yr, owing primarily to very small frequencies of occurrence. In spite of this, it may be considered that doses around the public dose limit are not acceptable, and that some optimisation of the repository design (e.g. deeper burial, use of a concrete cap to make human intrusions more difficult) is required.

A further issue that arises after excavation has taken place is the possibility that sealed sources that were disposed of in the repository are brought into the accessible environment, so that passers-by can pick them up as objects of interest, and remove them from the repository site. Calculations show that some of the sources are powerful enough to cause substantial radiation injuries, if handled by persons unaware of what they are. In view of this, it is recommended that a thorough examination is made of the sources to be disposed, and if significant sources are found, then consideration should be given to the removal of these sources (if possible), with a view to disposing of them in locations more robust against the effects of excavations.

E8.10.2 Natural Disruptive Event Scenarios

The natural disruptive event scenarios are the effects of:

- a transition to a wetter climate state
- gross erosion
- site flooding in the wetter climate state.

The critical groups assumed for these scenarios are settlers and nomads. The settlers are assumed to live a subsistence lifestyle in a farm or ranch that has the repository within its bounds, and the nomads are assumed to settle around the repository site and obtain their food from the area.

The doses arising from these scenarios are typically a few tens of micro-Sieverts, and conditional risks are around 2×10^{-6}/yr for all three scenarios. These conditional risks are therefore slightly in excess of the risk target of 1×10^{-6}/yr. However, the degree of belief associated with the occurrence of these scenarios is likely to be substantially less than unity and, when this is taken into account, individual risks will be compliant with the risk target.

E8.10.3 Scenarios Relating to Gas Pathway

The only gas pathway scenario is the effects of radioactive gas build up in a house on the repository.

The critical group assumed for this scenario is a settler family who occupy a house built on top of the repository. The family is assumed to occupy the house for 16 hours per day.

There are four radionuclides that are either gaseous in form, or which can form radioactively labelled gases that emerge from the repository. These are ^{3}H, ^{14}C, ^{85}Kr and ^{222}Rn. Assessment has shown that the risks posed by ^{3}H, ^{14}C and ^{85}Kr to occupiers of a house built on the repository are very small.

^{222}Rn, however, can emerge from the repository in significant quantities and, owing to the radiotoxicity of its progeny, can lead to substantial doses, in excess of 100 mSv/yr under worst-case conditions (cap eroded away, high diffusivity backfill materials). Additional computations with low diffusivity backfilling materials, such as concrete, suggest that ^{222}Rn doses to house occupiers would be reduced substantially. An engineered, multi-layer cap of 5 m thickness and suitable backfill material would mitigate the effects of ^{222}Rn emanation from the repository. However, this conclusion is contingent on the cap not acquiring fissures or cracks that might provide a preferential leakage pathway out of the repository.

E8.10.4 Leaching of Radionuclides in Groundwater

The groundwater pathway scenario considered here is the possibility that a severe rain storm infiltrates the repository, and causes radionuclides to be leached downwards through the unsaturated zone towards the underlying aquifer.

On the basis of reported groundwater calculations in (Bureau of Rural Science 2001), travel times through the unsaturated zone are tens of thousands of years. When the effects of radionuclide retardation are taken into account, it is found that only ^{129}I is capable of reaching the aquifer within around 10,000 years. A critical group consisting of individuals who extract water from a well drilled into the aquifer would receive a dose of less than 1 mSv/yr even if all of the ^{129}I were dumped into the aquifer, and they took a year's supply of water from the contaminated aquifer.

E8.10.5 Key Issues and Recommendations

The key safety issues that emerge from this assessment are:

I1. The radiological doses arising from some of the intrusion scenarios are in excess of the public dose limit of 1 mSv/yr. In a risk-based assessment, this is offset by comparatively low probabilities of occurrence. Nevertheless, consideration may need to be given to optimisation of repository design, in order to reduce the magnitude of these conditional doses. In ICRP Report 81 (1998), it is recommended that a conditional dose of 10 mSv/yr is the limit above which optimisation studies should be undertaken, in the context of human intrusion activities affecting a repository.

I2. The largest conditional risks arise from a scenario in which a wetter climate is assumed to occur. However, current research suggests that such a climate is unlikely to occur within the time period of the assessment (10,000 years – see Section E8.3.1) and so a comparatively low degree of belief would be attached to this scenario.

I3. In some circumstances, doses arising from inhalation of ^{222}Rn and its progeny can exceed 100 mSv/yr, for occupants of a house built on top of the repository. Calculations show that the use of appropriate materials, and design, for the cap and backfill will reduce these doses to negligible levels.

I4. The radiological consequences of someone removing a sealed source from the repository (for example after waste has been excavated) could be considerable, in particular for some of the substantial ^{137}Cs sources that are present. Near-surface disposal may not be suitable for such high-activity sources.

In the light of these issues, and consideration of the approach and data used in this assessment, the following recommendations are made for further work.

R1. The scenarios considered in this work should be re-examined, in conjunction with the tree structure shown in Figure E8.3.2, to ensure that no potentially important scenarios have been omitted from consideration.

R2. In this assessment, doses and risks have been compared with a dose limit of 1 mSv/yr and a risk target of 1×10^{-6}/yr, respectively. In the case of human intrusion scenarios, doses have also been compared with intervention levels given in ICRP 81 (1998). It is recommended that a clearer view of the regulatory framework is achieved through appropriate consultation, in particular relating to human intrusion and performance measures other than risk.

R3. If a risk-based approach is to be retained for the examination of radiological consequences of human intrusions, then a thorough examination of historical data should be undertaken, to ensure that adopted frequencies of occurrence for the various intrusions are based on the best available data, rather than plausible estimates.

R4. Some of the human intrusion scenarios lead to effective doses in excess of 1 mSv/yr. Consideration should be given to optimisation of the repository design (e.g. a more robust cap), to reduce the magnitude of these doses and the probability of intrusions occurring.

R5. In order to identify consumption rates of various foodstuffs (both plant and animal) for settlers and nomads, appropriate literature was consulted, as discussed in Section E8.5. However, this information tended to reflect Australian national averages, rather than the human population in and around the Woomera area. It might be useful to consider more local habit surveys, rather than national averages.

R6. Exposure times for Aboriginal and other nomadic groups who may settle in the vicinity of the repository site are based largely on anecdotal evidence, rather than specific analyses of the habits and behaviour of local tribes. It is recommended that, if possible, local tribal behaviour should be examined and used to determine likely exposure times.

R7. Consideration should be given to the use of an appropriately designed cap and concrete backfill. A concrete cap will serve both to make human intrusions more difficult, and so allow ^{222}Rn to decay completely before reaching the ground surface. Concrete backfill will serve to mitigate the effects of ^{222}Rn when the cap has eroded away.

R8. Consideration should also be given to removal of very high activity sources from the current waste inventory, with a view to disposal in a manner that is more robust against the effects of excavations. It should of course be noted that the use of a concrete cap at the present site would improve the robustness of the facility in this way.

R9. The hydrological approach to estimating groundwater travel times through the unsaturated zone involves the use of chloride mass balance arguments, and provides data that corresponds to an average over an area somewhat larger than the repository footprint. It is recommended that additional studies are undertaken to provide confidence that such long travel times persist at the location of the repository itself.

E8.11 References

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APPENDIX F

Appendix F

ASSESSMENT OF CLIMATIC CHANGE AT WOOMERA

CSIRO Atmospheric Research

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Appendix F
Assessment of Climatic Change at Woomera

This appendix reports on the results of climatic simulations carried out with a variety of CSIRO climatic models to assess the potential impact of possible climate changes on the integrity of a proposed radioactive waste disposal facility at Woomera, South Australia.

F.1 Introduction

In assessing the various factors that may influence the integrity of disposal facilities for radioactive waste, it is necessary to consider climatic influences because of the extremely long lifetime of components of this waste. For the purposes of this study, a maximum timeframe of 10,000 years has been stipulated by the contractors. Climate can affect such facilities in a number of ways, such as changes in rainfall amount and extremes, variations in soil moisture content, recharge of surface and aquifer watertables, soil erosion by floods and winds and also temperature changes. All of these factors may influence vegetation in the vicinity of a disposal facility.

Some details of the location and construction of the proposed disposal facility are provided in Figures F.1, F.2 and F.3. The preferred site, Site 52a in Figure F.1, is in an arid region of central South Australia, within the Woomera Prohibited Area. The site plan, Figure F.2, shows that a buffer zone of 1.5 x 1.5 km would be reserved around the 100 x 100 m disposal facility. This region of Australia has low rainfall and high evaporation, and thus very little water available for infiltration into the soil. The geology of the site, Figure F.2, indicates that the soil structure is made up of a succession of layers of clay, shale and sandstone. As indicated in Figure F.2 and Figure F.3 the waste would be buried in steel or concrete drums in trenches up to 20 m deep. Surface water or groundwater entry into these trenches would be prevented.

FIGURE F.1
Location of preferred site (52a) for national radioactive waste repository

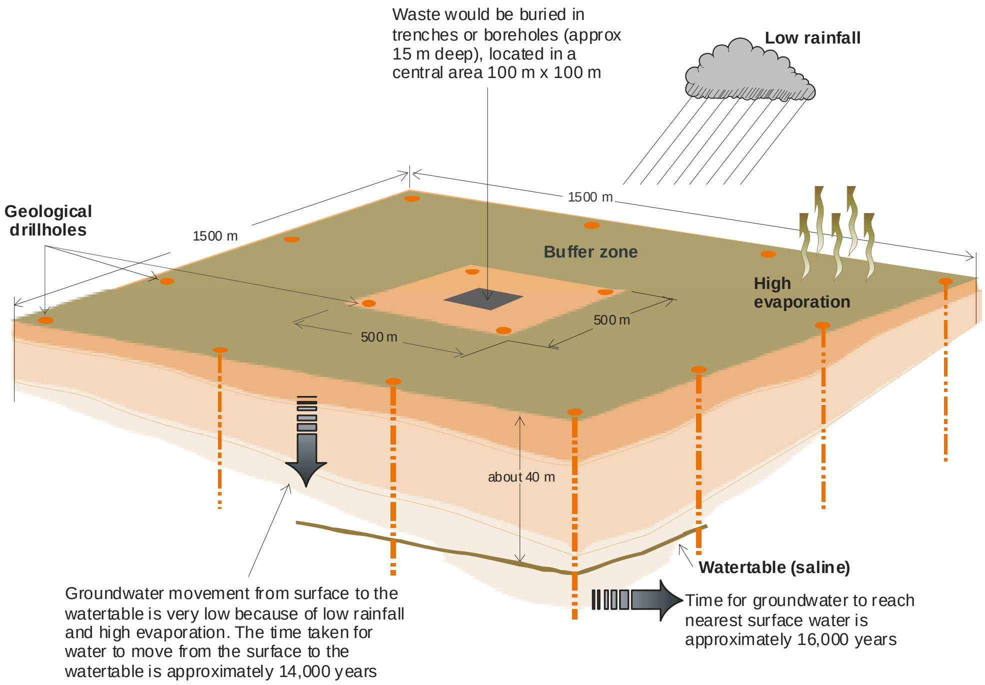

FIGURE F.2
Schematic diagram of Site 52a indicating dimensions and geology

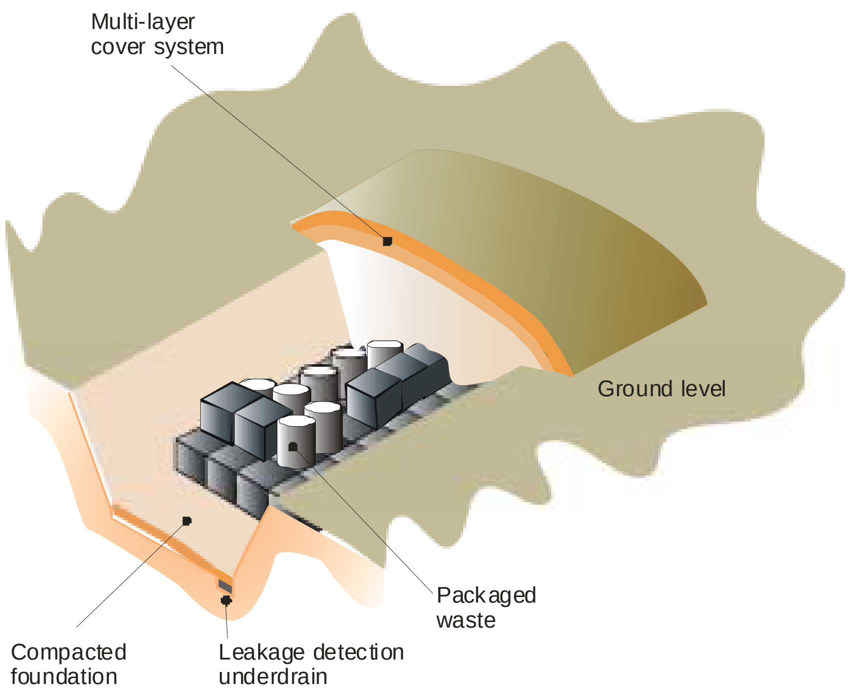

FIGURE F.3
Indicative trench design

There are three primary climatic issues relevant to this facility, namely greenhouse-induced climatic change, naturally occurring climatic variation and very long term climatic perturbations associated with multi-millennial scale changes in the occurrence of volcanic eruptions, solar perturbations and orbital variations of the Earth (the so-called Milankovitch effect).

The greenhouse effect (or more precisely the enhanced greenhouse effect) is caused by increasing atmospheric concentrations of gases such as CO_2, O_3, CH_4 N_2O and chlorofluorocarbons owing to anthropogenic activities. The most important of these gases is CO_2, of which six billion tonnes is currently released into the atmosphere each year. Future projections for the release of CO_2 suggest that this annual release could double or triple over the next century depending primarily on the growth in economic activity world-wide.

The timeframes associated with the greenhouse effect are in the order of decades to centuries for the immediate responses to increasing greenhouse gas concentrations, with residual responses lasting centuries as the climate responds to the subsequent adjustments in these gas concentrations (Intergovernmental Panel on Climate Change, 2001).

As is well-known, the climate varies from year-to-year and decade-to-decade. Such variations occur without any external influences and are attributable to the natural vagaries of the climatic system, which has many interacting feedback influences. This natural climatic variability can have quite substantial impacts, for example there is currently a 30-year drying episode in the southwest of Western Australia which is causing considerable local problems.

While the usual timeframe for natural climatic variability tends to be measured in years to decades, more subtle interactions between the atmosphere and the oceans can occur over the timescale of centuries or millennia. Such interactions may be associated with such climatic features as the so-called Little Ice Age and Medieval Climatic Optimum (Hunt, 1998). In the case of the Milankovitch Effect, the timeframes are, of course, typically measured in multi-millennia.

A more detailed list of mechanisms and timeframes relevant to climatic change is given by Goodess et al. (1992).

Increasingly comprehensive documentation of observed palaeoclimates is being developed which provides insights over a range of timescales, climatic states and transitions. A useful summary of current knowledge is provided in Chapter 2 of Climate Change 2001 (Intergovernmental Panel on Climate Change 2001).

This summary identifies major climatic transitions at approximately 120,000 year intervals, presumably associated with the Milankovitch effect, but with much smaller impacts in the southern hemisphere. Over the past 25,000 years the amplitudes of climatic perturbations have been smaller, but substantial transitions between different climatic states occurred. Changes in the nature of El Niño–Southern Oscillation events, which markedly affect Australian climate on an interannual timescale current, have also been identified. Presumably, the climate in the Woomera region also varied as part of the above climatic perturbations, but appropriate palaeoclimatic analyses are required. Nevertheless, aridity appears to be the dominant climatic characteristic of this region over the past several thousand years.

These various climatic perturbations can be studied with coupled global climatic models that replicate the observed climatic system. For example, a typical model now consists of atmospheric, oceanic, biospheric and sea-ice components. The atmospheric and oceanic components each have a number of vertical levels that are divided into gridboxes distributed over the Earth. At each gridbox the relevant climatic terms are computed and progressed into the future (typically at 15-minute intervals) thereby permitting century or millennial simulations of the climatic system to be made.

The present study uses results from a number of CSIRO models run for a range of climatic situations. The basic global climatic models are referred to as the Mark 2 and Mark 3 versions of the CSIRO climate model. The Mark 2 version has nine vertical levels in the atmosphere, 21 in the ocean, and approximately 3600 gridboxes in the horizontal. A rather simple surface layer scheme is used to represent biospheric processes. In contrast, the Mark 3 model has considerably improved schemes to represent atmospheric and oceanic processes, particularly as regards the biosphere. The atmospheric component has 18 vertical levels, the ocean 31, and over 18,000 gridboxes in the horizontal.

In addition, the CSIRO regional model, known as DARLAM, is used to obtain a finer scale resolution (of 125 km) over Australia than can be produced with the global climatic models. Such fine scale usually equates to more accurate simulations. DARLAM simulations have only been performed with output from the Mark 2 model to date.

This study opportunistically takes advantage of a number of climatic simulations made for a variety of purposes. For clarity, each section of the report will briefly describe the experiment and model used to generate the results presented in that section.

F.2 Simulations with the CSIRO Mark 2 Model Involving Climatic Change Scenarios

One of the principal uncertainties associated with the greenhouse effect is quantification of future CO_2 emissions. Consequently, a range of possible CO_2 emission scenarios has been proposed, which are known as the SRES (IPCC Special Report on Emissions Scenarios) cases. The CSIRO Mark 2 coupled model has been used to quantify climatic changes out to 2100 AD based on four SRES cases, known as A1, A2, B1 and B2. These cases involve different atmospheric CO_2 concentrations as shown in Figure F.4. The CO_2 concentrations in Figure F.4 are expressed as 'equivalent' CO_2. This means that the various radiative gases involved, CO_2, O_3, CH_4, N_2O etc., have been combined to produce a CO_2 concentration that is 'equivalent' to the sum of all these gases. On this scale the pre-industrial CO_2 concentration for 1880 is about 310 ppmv. The SRES concentrations at 2100 AD range between 800 ppmv and 1400 ppmv, indicating the significant changes in equivalent CO_2 concentrations expected, as well as the diversity between these SRES cases.

As noted above the CSIRO simulations using the SRES cases terminated at 2100 AD, as CO_2 concentrations for these cases after this time do not exist. However, Walker and Kasting (1992) have devised atmospheric CO_2 concentrations extending far into the future. These indicate CO_2 concentrations of up to 2000 ppmv some centuries ahead, followed by a steady decline over some millennia, as fossil fuel reserves are exhausted and the CO_2 is absorbed back into the environment. Global climatic model simulations appropriate to such scenarios do not currently exist, consequently it is unknown how this might affect climatic conditions in the Woomera region. However, it is highly questionable whether international concerns would permit such extreme CO_2 concentrations to be achieved in practice.

Each of the SRES cases is associated with a corresponding atmospheric sulphate aerosol distribution. These aerosols influence the climatic response by interacting with the incoming solar radiation or modifying cloud properties. Owing to uncertainties associated with such cloud effects only the solar, or direct aerosol, response is included here. The impact of the aerosol is then to reduce the greenhouse warming by reflecting incoming solar radiation.

The various aerosol concentrations are illustrated in Figure F.5, where the time variations imply the application of controls on sulphur dioxide emissions from fossil fuel. The interplay between the CO_2 and sulphate emissions has a complicated influence on the resulting greenhouse-induced climatic warming, hence impacts over the timeframe to 2100 AD are not necessarily directly related to the CO_2 concentrations in Figure F.4.

The range of simulated increases in global mean temperature by 2100 AD shown in Figure F.6 indicates the uncertainty in climatic outcomes attributable to uncertainties in CO_2 emission rates. These emission rates depend on economic growth, as well as possible global actions to reduce emission rates or enhance removal of CO_2 from the atmosphere. Consequently, any simulated climatic impacts can only be quantified within these uncertainty limits.

There is also an additional source of uncertainty arising from the different sensitivities of global climatic models to greenhouse forcing. These create a range of uncertainty in the climatic changes for a given CO_2 emission rate. For a given CO_2 scenario, global mean temperature increases at 2100 AD can be spread over a range of 2º to 6°C owing to such sensitivities. The CSIRO Mark 2 model has one of the higher sensitivity responses, implying larger temperature increases than some other models.

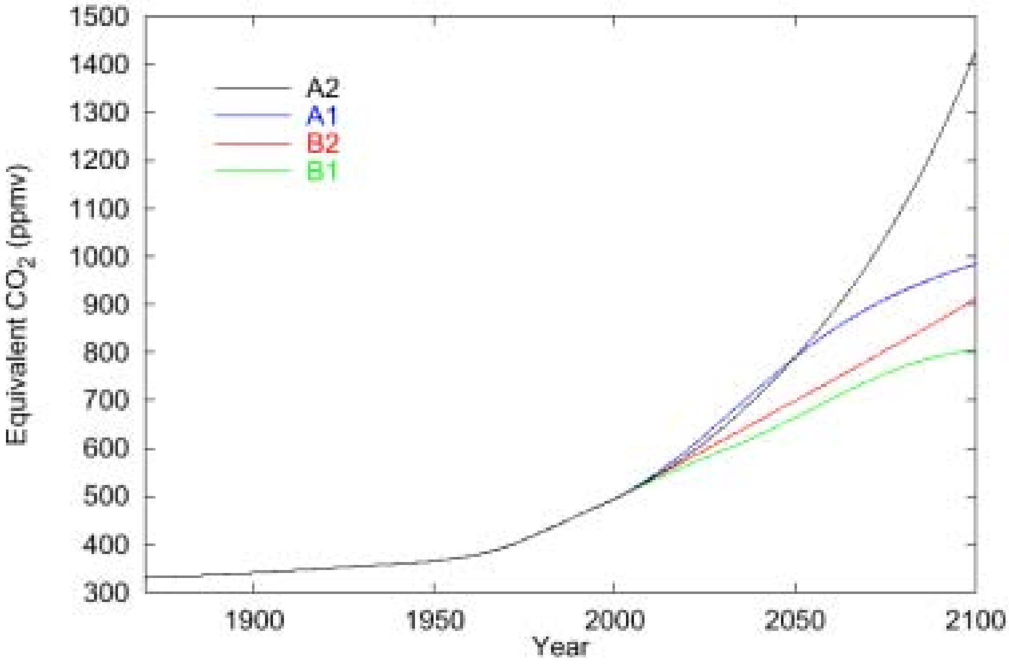

FIGURE F.4
Equivalent atmospheric CO_2 concentrations for the four SRES scenario members

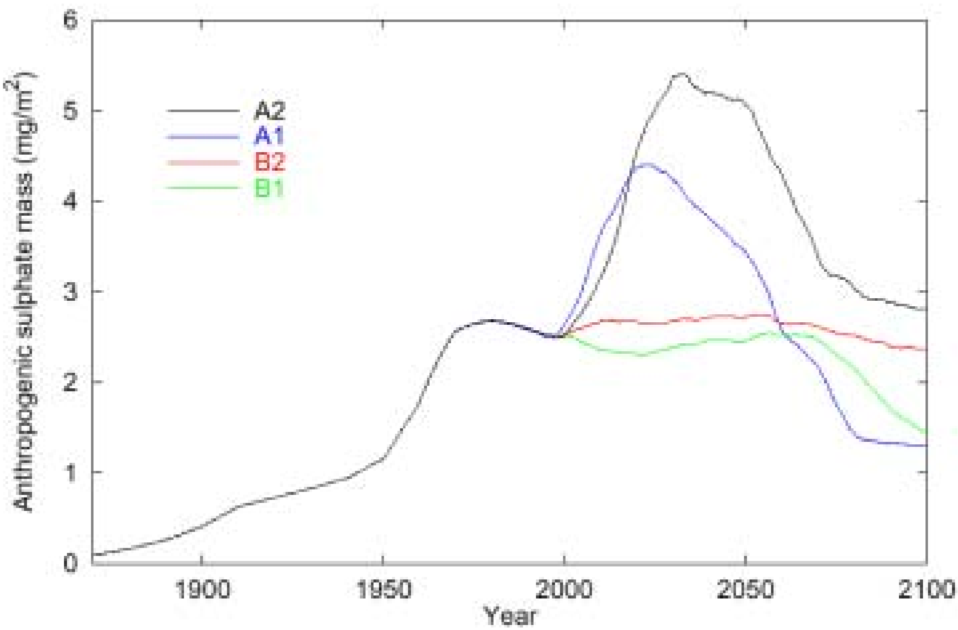

FIGURE F.5
Annual mean sulphate aerosol burdens for the four SRES scenario members

As shown in Figures F.4 and F.5 the CO_2 and sulphate concentrations associated with the various SRES cases only diverge after 1990. The climatic simulation for the SRES cases was actually started in 1880, and was run forward using observed CO_2 and sulphate concentrations to 1990. At this time the individual SRES runs were commenced. Thus from 1880 to 1990 AD all SRES cases have a common time history.

Figure F.6 compares the temporal variability of the annually averaged, global-mean, surface air temperature anomalies for the four SRES cases and observations. The agreement between the simulation and the observations up to 1990 reveals that the model captures the basic observed characteristics quite well. All cases exhibit a growing temperature trend, attributable to the greenhouse effect, upon which is superimposed noticeable interannual perturbations resulting from natural climatic variability. The temperature increases at 2100 AD range between 3.0 K for B1 to 4.5 K for A2. These values reflect the final CO_2 concentrations shown in Figure F.4, but, as can be seen from Figure F.6, the individual variations over time are more varied, reflecting the different variations of the sulphate concentrations shown in Figure F.5.

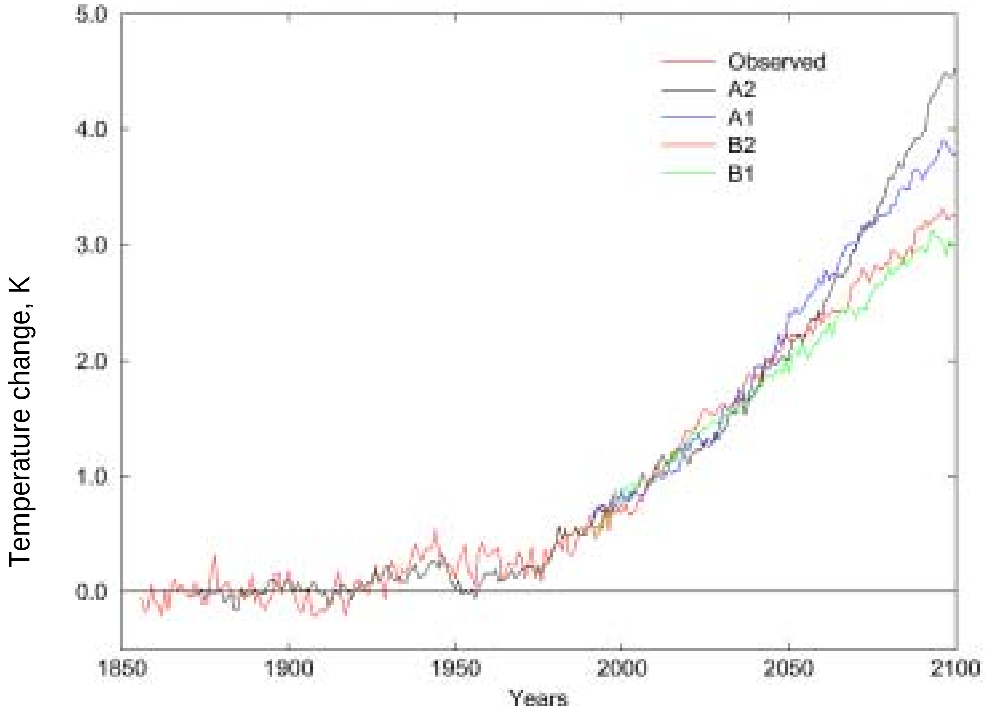

FIGURE F.6
Global-mean, annually averaged screen temperature anomalies for the four SRES scenario members, together with observations up to 2000 AD

The spatial pattern of a given climatic change varies between the four SRES cases, introducing an addition source of complexity. Figure F.7 compares surface temperature changes over the Australian region for the SRES cases derived as the difference of the average over years 2070 to 2100 AD minus the average over years 1960 to 1990 AD. Thirty-year averages are used to smooth over the interannual variability. The figure shows that there is a general warming over Australia and the adjacent oceans, approximately proportional to the final atmospheric CO_2 concentrations in Figure F.4. As might be expected the largest temperature increase occurs over inland Australia.

The corresponding rainfall changes for the Australian region are given in Figure F.8. Some commonality can be seen between the various cases, with enhanced rainfall in the north and reduced rainfall in the south of Australia. Except for the B2 case in Figure F.8, the rainfall changes scale reasonably in accordance with the CO_2 concentrations in Figure F.4. Note that over South Australia there is a fairly uniform decline in rainfall across all four SRES cases, although the magnitude is quite small, $\approx$ 0.1 to 0.2 mm/d.

The rainfall for a model gridbox over the Woomera area exhibits large differences in year-to-year values and between the SRES cases for a given year, see Figure F.9. Thus, while the overall climatic trend under greenhouse conditions for the Woomera region is for a slightly drier situation, the possibility still exists that in any one year heavy rainfall events can occur. Clearly climatic variability is more dominant than climatic change in this example.

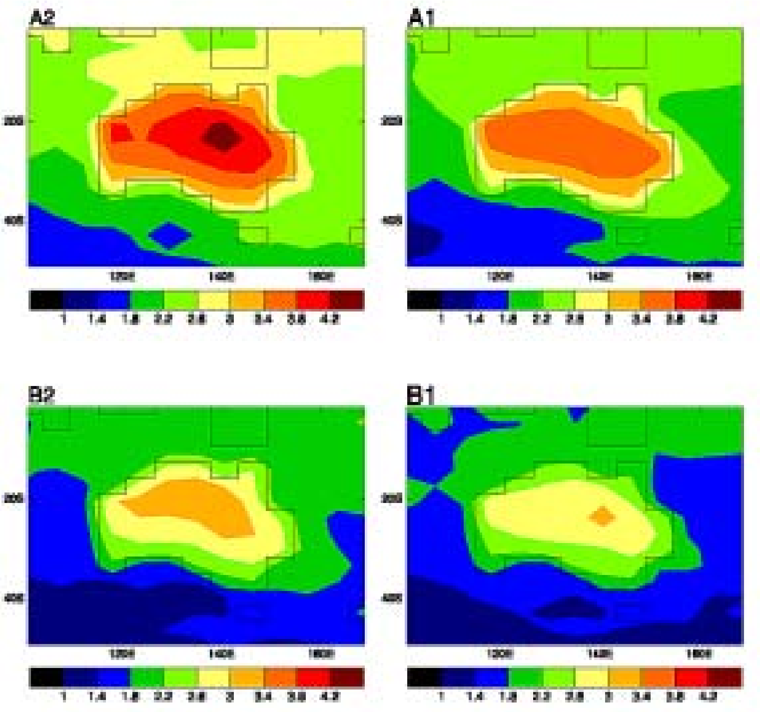

FIGURE F.7
Temperature anomalies for the four SRES scenario members defined as the difference between the annual means of years 2070 to 2100 AD minus the annual means of years 1960 to 1990 AD (bar coding is in K)

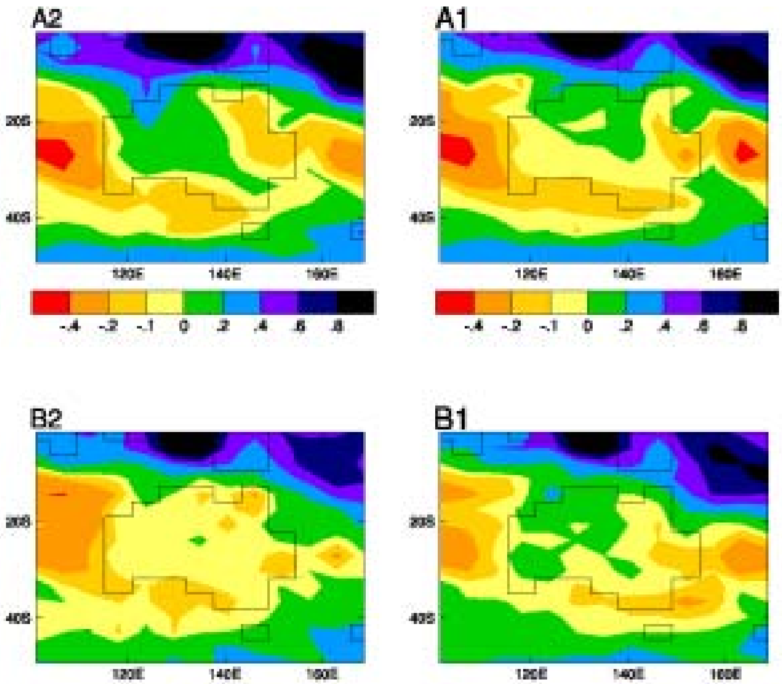

FIGURE F.8
Rainfall anomalies for the four SRES scenario members defined as the difference between the annual means of years 2070 to 2100 AD minus the annual means of years 1960 to 1990 AD (bar coding is in mm)

As will be discussed below, (Section F.4) the temporal variability for the greenhouse runs illustrated in Figure F.9 is within the range of natural climatic variability for this model. The corresponding soil moisture values for the Woomera grid box, ≅ 0.1, are very low as shown in Figure F.10. A rather simple biospheric scheme is used in the Mark 2 model, consisting of two soil layers with nine different soil types and thirteen plant types. These types are constant within a given model gridbox. Each soil type has its own soil property characteristics, which affect the water-holding capacity of the soil. Figure F.10 indicates that the soil moisture content is essentially time invariant across the four SRES cases out to 2100 AD, but with noticeable interannual variability, associated with the corresponding rainfall variability in Figure F.9. The relative dryness of the soil at Woomera can be judged from the fact that values up to 0.4 are achieved in high rainfall regions in Australia.

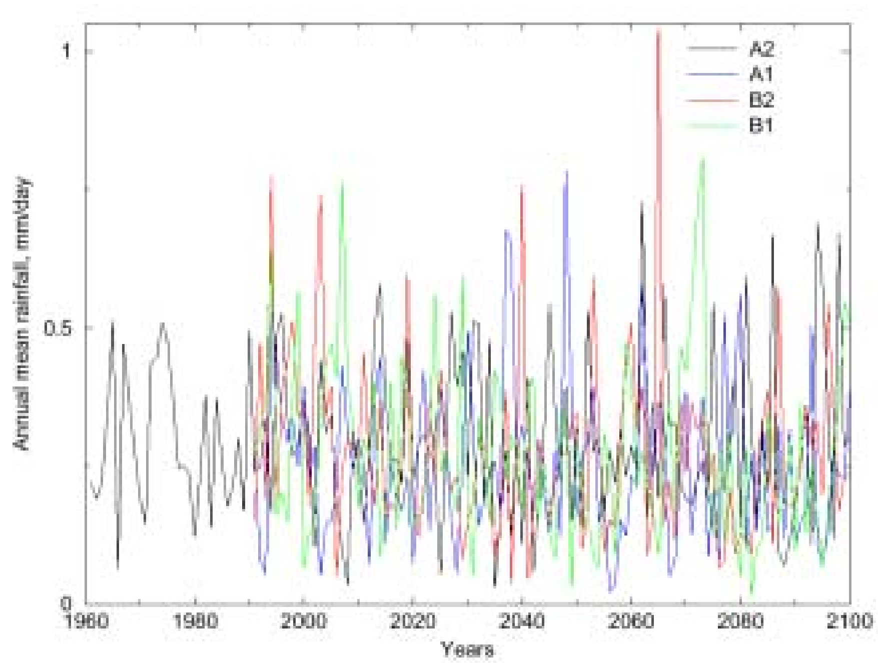

FIGURE F.9
Annual mean rainfall for the four SRES scenario members for Woomera

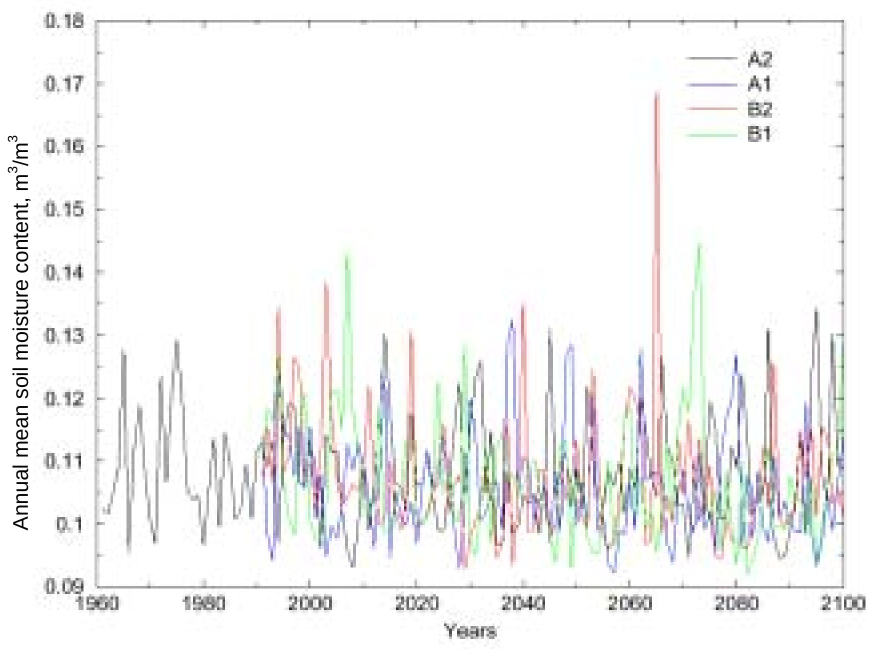

FIGURE F.10
Annual mean soil moisture content for the four SRES scenario members for Woomera

Time smoothing of the curves in Figures F.9 and F.10, which removes the high frequency variability, indicates in each case long term trends of slightly reduced rainfall and soil moisture.

Overall, these results suggest a stable climatic situation for the Woomera region as regards its hydrologic characteristics for the SRES greenhouse cases considered here. When this hydrologic situation is considered in conjunction with the increasing temperatures (Figure F.7), this suggests a deterioration in agricultural conditions in the Woomera region.

Changes in surface wind speed in the Woomera region could cause soil erosion during exceptionally dry periods and produce large-scale dust clouds. The surface (≈ 2 m height) wind speeds for the SRES cases are illustrated in Figure F.11 for Woomera. Annual mean winds have been used, which eliminates daily or seasonal extremes, but the object of the figure is to identify any trend in wind speed associated with the greenhouse effect. The figure reveals a rather stable state with wind speeds varying by less than 1 m/s over the course of the simulations. This indicates that no wind erosion greater than that which occurs at present might be expected in the future according to these simulations. However, soil erosion is generated by extreme events of short duration, a day or less, and a more thorough assessment would require simulated wind data at such time spans, which are not available from the current simulations. A more detailed discussion of surface wind distributions is given in Section F.4. A previous report on conditions at Maralinga under greenhouse conditions also provides a more comprehensive analysis (Hunt and Elliott 2001).

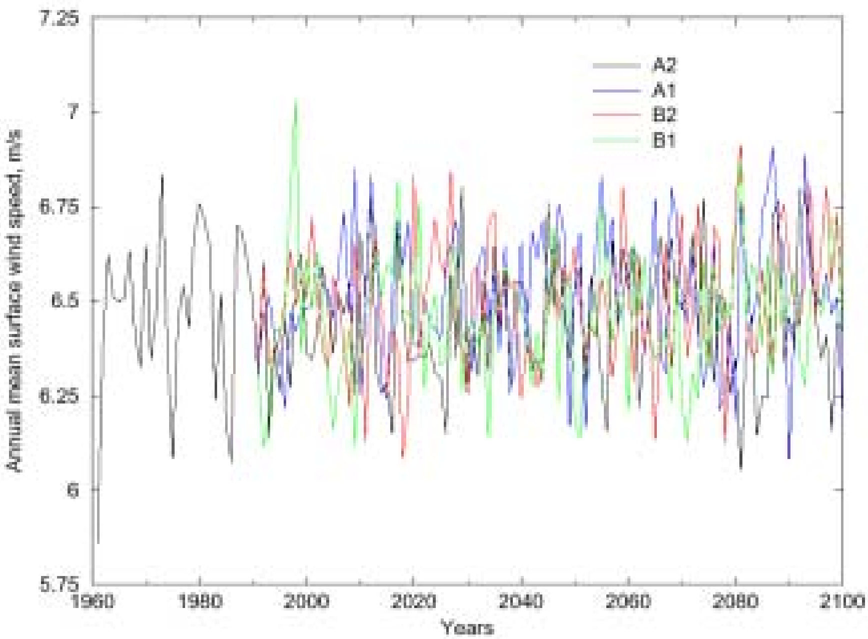

FIGURE F.11
Annual mean surface wind speed for the four SRES scenario members for Woomera

An aspect of these simulations which is remote from Woomera, but which could cause global scale climatic perturbations, is that associated with the so-called ‘meridional overturning’ in the North Atlantic ocean. This is potentially one of the most critical changes obtained in simulations of greenhouse-induced climatic change. This overturning is a consequence of the sinking of cold, salty water near Greenland, which induces an upper oceanic polewards flow of water to replace it. A component of this flow is the Gulf Stream that warms Europe and ameliorates its climate.

The changes in this overturning during the SRES simulations is shown in Figure F.12, where it can be seen that under all scenarios the magnitude of the overturning greatly diminishes. Because of the established interconnections between the oceans, this change in the North Atlantic overturning will have some impact on the other oceans and their circulations. Such impacts are naturally included into the climatic responses which occur elsewhere on Earth, and, to the extent that they may influence the climate over Australia, they are incorporated in the model simulations presented here.

The reason that changes in overturning are of concern is because they may be linked to relatively sudden and substantial changes in past climate, at least in the northern hemisphere, deduced from oceanic sedimentary cores. If this is the case, the possibility exists that the appropriate climatic response to such overturning events is not being adequately replicated by the models.

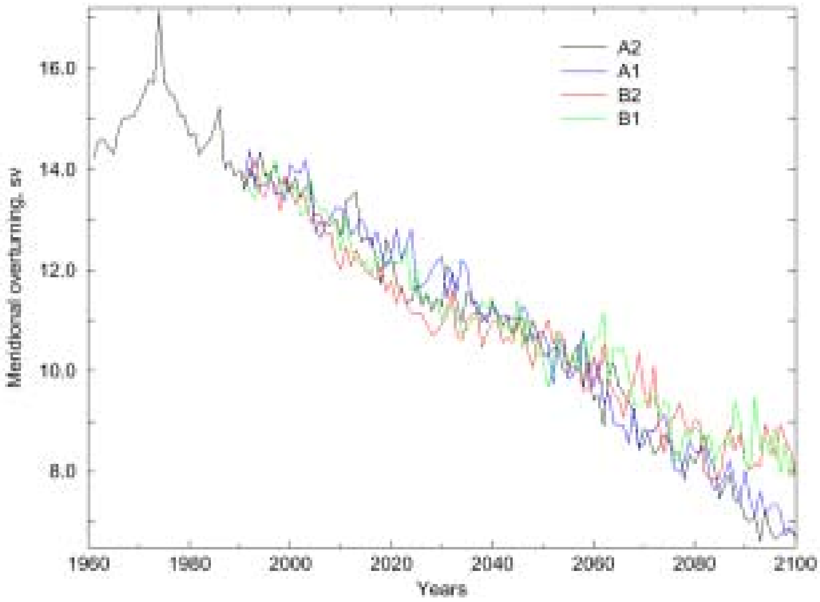

FIGURE F.12
Meridional overturning stream function for the North Atlantic Ocean for the four SRES scenario members

F.3 Extended Greenhouse Simulation with the CSIRO Mark 2 Model

Because of the large thermal inertia of the oceans the climatic system has a very long response time. Thus if greenhouse gases in the atmosphere were stabilised at, say, an equivalent 2×CO_2 concentration, the climatic system would still continue to warm as an equilibrium state would not have been achieved at the time the gas concentration stabilised. Climatic warming, and consequently other climatic impacts, would continue to occur for some hundreds of years. To explore this situation the CSIRO Mark 2 global climatic model has been integrated forward starting from 1870 AD. Observed equivalent CO_2 concentrations were used up to 1981 AD when the equivalent CO_2 concentrations defined by the IS92a scenario were specified, until a doubled equivalent CO_2 concentration was attained in 2033 AD. This CO_2 concentration was then held constant for the next 600 years. No atmospheric aerosols were incorporated in this simulation, hence the atmospheric warming rates were larger than those obtained in the previous SRES cases. (The IS92a scenario is fairly similar to the A2 scenario shown in Figure F.4.)

The rainfall and soil moisture for Woomera are shown together in Figure F.13 for the period commencing in 1981. The two time series are highly correlated (0.9), as might be expected, but no distinct trends are apparent over this extended period. The most noticeable feature in the figure is the marked interannual variability attributable to natural climatic variability.

While Figure F.13 indicates a rather stable hydrological situation for Woomera, this is not the case for Australia as a whole. Figure F.14 highlights the changes in rainfall from present climatic conditions at the time equivalent CO_2 doubled, and at the end of the simulation. The top panel in Figure F.14 shows a mixed pattern of rainfall change over Australia having some similarities with the four previous SRES cases shown in Figure F.8. (Remember, each SRES case had a different equivalent CO_2 distribution and also an aerosol distribution, hence the greenhouse forcing would have substantial differences to the present simulation.) Interestingly, by 2600 AD, rainfall over most of Australia decreases, especially in Queensland.

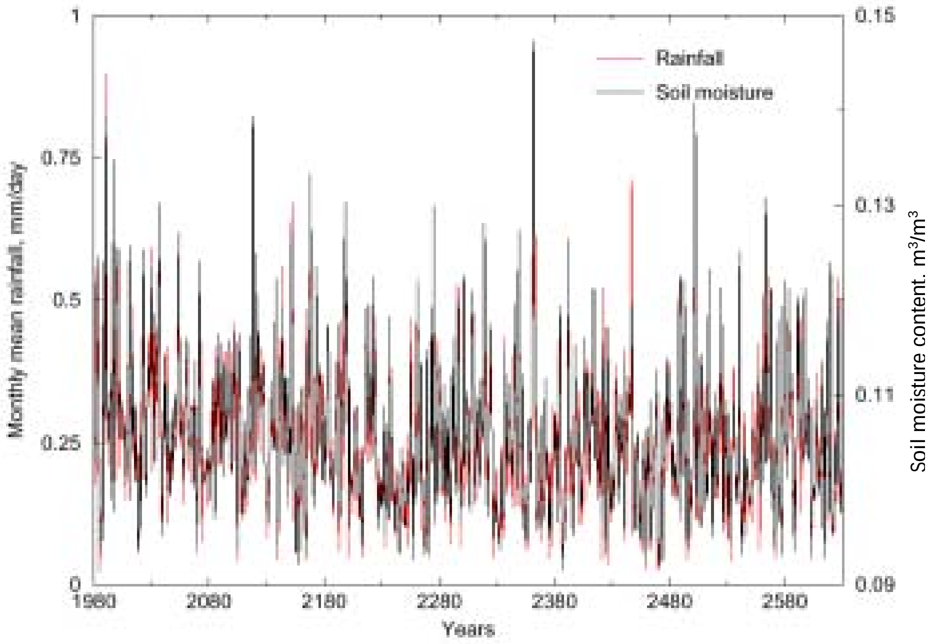

FIGURE F.13
Monthly rainfall and soil moisture content for Woomera from the extended greenhouse simulation

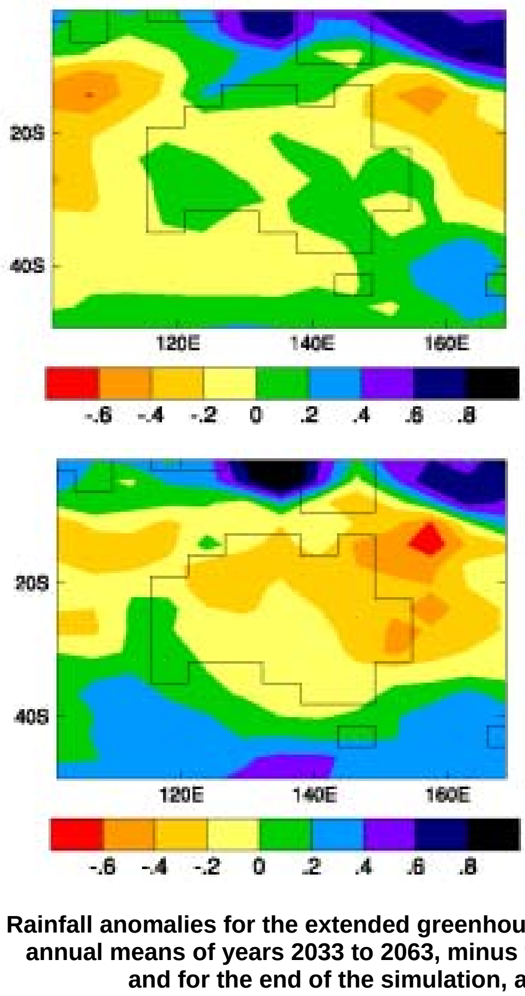

FIGURE F.14
Rainfall anomalies for the extended greenhouse simulation for the time of doubling of CO_2, annual means of years 2033 to 2063, minus the annual means of years 1951 to 1980 (top), and for the end of the simulation, annual means of years 2600 to 2630 minus the annuals means of years 1951 to 1980 (bottom) (bar coding is in mm/d)

Thus Australia as a whole is simulated to be more arid. While it would be valuable to extend the four SRES simulations further into the future, corresponding to the situation presented here, the problem is knowing how to specify the individual CO_2 distributions shown in Figure F.4 past 2100 AD.

In Figure F.15 time series of Woomera surface temperature, together with a repeat of the rainfall time series from Figure F.13, are plotted for the total duration of this extended simulation. This figure contrasts the relative stability of rainfall compared to the noticeable increase in surface temperature. The surface temperature increases from an initial annual mean value of about 294 K to about 296 K at the time of doubling in 2033 AD. Despite the subsequent constancy of the atmospheric CO_2 concentration, the surface temperature continues to increase to a value of about 298 K as the climatic system eventually attains a new ‘equilibrium’ status. Superimposed upon the trend of increasing temperature is a marked interannual fluctuation associated with natural climatic variability. Thus a simple year-on-year monotonic temperature increase is not to be expected. This result emphasises the very long timescales associated with changes in atmospheric CO_2 content. Importantly, it needs to be appreciated that stabilisation of the CO_2 content does not imply a simultaneous stabilisation of the climatic system.

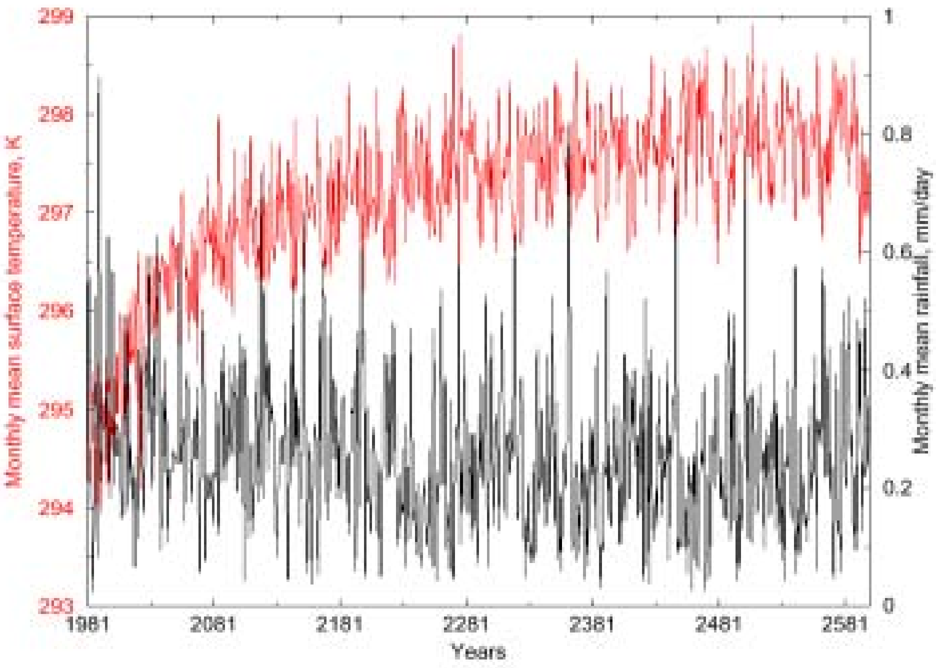

FIGURE F.15
Monthly rainfall and surface temperature for Woomera from the extended greenhouse simulation

F.4 Millennial Simulation for Present Climatic Conditions with the CSIRO Mark 2 Model

A 10,000-year long simulation has been made with the CSIRO Mark 2 global climatic model for present climatic conditions, i.e. no variations in CO_2 concentration, volcanic activity or solar variability. This simulation was made to investigate the magnitude of natural climatic variability attributable solely to the intrinsic chaotic properties of the climatic system.

This simulation permits a *quantitative* estimate to be made of the range of climatic fluctuations likely to be encountered under ‘normal’ conditions, and, importantly, identification of climatic extremes. It is extreme conditions that could pose a hazard to any disposal facility.

In Figure F.16 the temporal variation of annual-mean rainfall values at Woomera is illustrated for the first and ninth millennia of this simulation. The first millennium (top panel of Figure F.16) was typical of most of the simulation and reveals noticeable interannual variability. An evaluation of all 10,000 years showed that there were 25 occasions when annual-mean, rainfall peaks reached 0.8 mm/d or more, implying a return period of 400 years. Typically, these peaks were not uniformly distributed with time; some millennia having only one peak and one millennium none. The ninth millennium (last panel of Figure F.16), shows a more quiescent state, but with marked outliers occurring around 8450 years. These outliers had the most extreme rainfall for Woomera in the whole of the simulation. The situation portrayed in this panel illustrates an interesting aspect of climatic variability, e.g. in the middle of a 'quiet' climatic era an extreme event can occur. The annual mean rainfall distribution over Australia for the year with the most extreme outlier, year 8442, is shown in Figure F.17(b), while Figure F.17(a) illustrates the corresponding rainfall distribution for an earlier year when Woomera rainfall was near average. In fact, the Australian rainfall distribution shown in Figure F.17(a) is quite similar to the observed climatic mean. The anomalous conditions in Figure F.17(b) shows a rainfall increase extending from the northeast of Australia. Thus the rainfall extreme at Woomera was part of a large-scale climatic perturbation rather than a localised climatic feature.

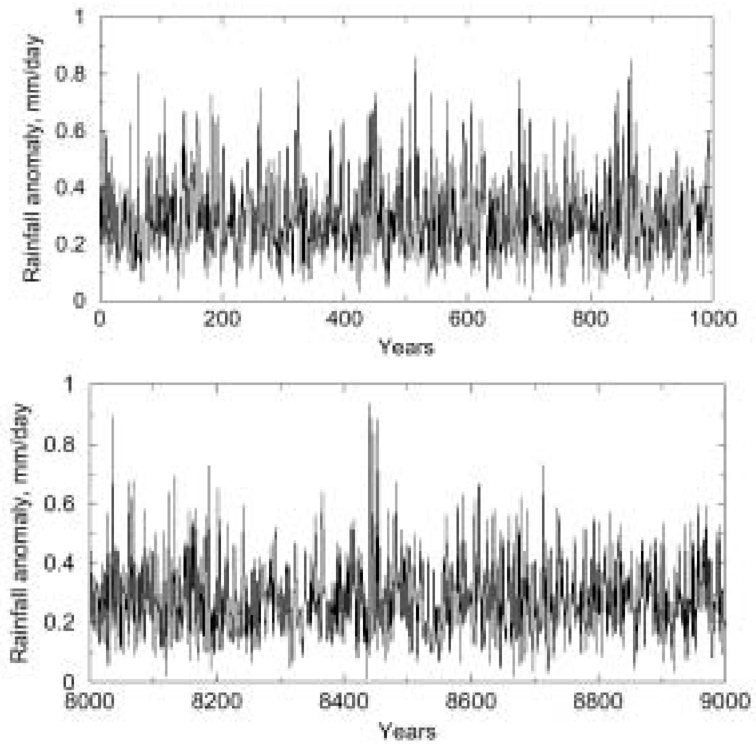

FIGURE F.16
Annual mean rainfall for Woomera for two separate millennia of the 10,000-year simulation

Examination of the global distributions of the surface temperature anomalies for these two years revealed that year 8442 was associated with a warming of up to 2 K over a large area of the central Pacific Ocean primarily south of the Equator. In contrast, year 8419 was cooler by up to 2 K over much of the central Pacific Ocean. The rainfall changes in Figure F.17 are, at least partially, driven by these oceanic temperature changes. The latter, in turn, result from nonlinear interactions within the climatic system and are part of its natural variability.

The peak rainfall at Woomera for year 8442 was 0.938 mm/d, and was thus 3.3 times the average rainfall of 0.286 mm/d. However, as can be seen from the first millennial time series in Figure F.16, rainfall outliers of 0.8 mm/d occurred several times in this millennium. Such outliers are equivalent to rainfall amounts of 2.8 times the average rainfall. Thus the extreme rainfall amount for year 8442 does not represent an inordinate increase compared with these 'more typical' outliers.

The SRES greenhouse rainfall time series in Figure F.9 reveals only one extreme outlier, for the B2 case, where rainfall exceeded 1 mm/d. A few other outliers reached 0.8 mm/d.

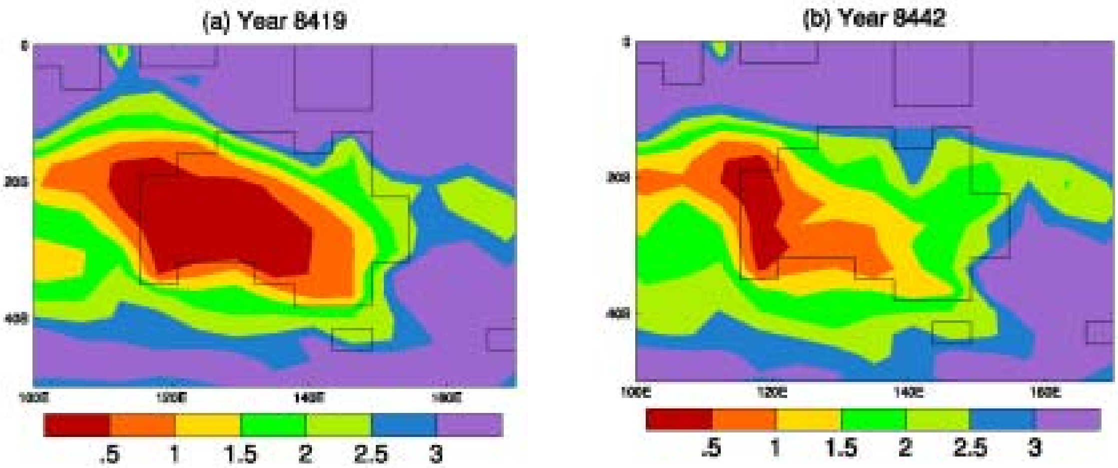

FIGURE F.17
Examples of extreme annual mean rainfall.
Year 8419 (left) had near average rainfall for Woomera,
year 8442 (right) had one of the wettest years for Woomera (bar coding is in mm/d)

This combination of results for greenhouse-induced climatic change and natural climatic variability, suggests that extreme rainfall perturbations much above those associated with natural climatic variability should not be expected under greenhouse conditions for Woomera. Hence, a disposal facility designed to cope with natural climatic variability should be adequate to withstand any hydrologically induced erosion problems. However, see Section F.7.

The soil moisture content time series corresponding to the rainfall time series in Figure F.16 are shown in Figure F.18. As would be expected following the results in Figure F.13, the two time series are highly correlated. However, the peak soil moisture content is typically only 50% higher than the mean value, indicating how little rainfall is available for recharging the soil moisture at Woomera. Thus, the basic aridity of this region is maintained during this 10,000-year simulation.

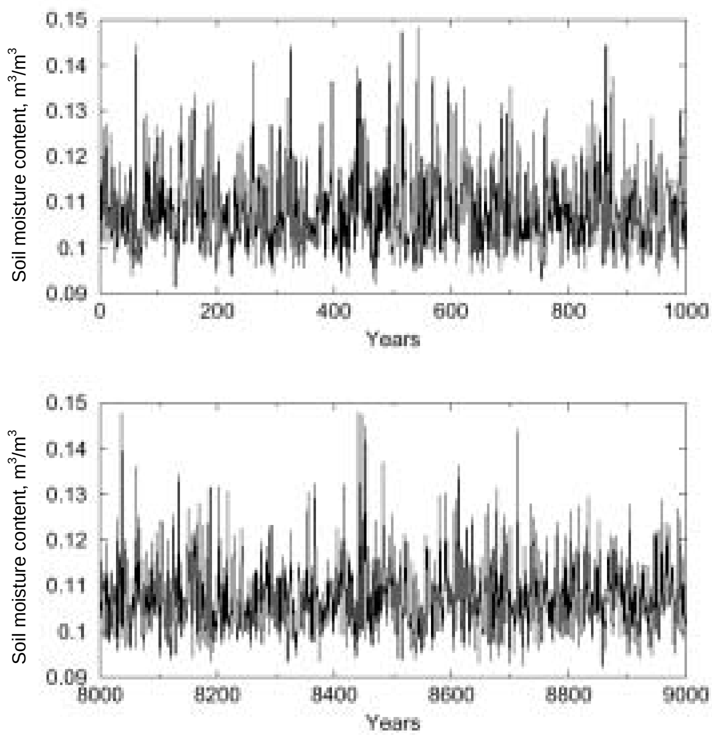

FIGURE F.18
Annual mean soil moisture content for Woomera corresponding
to the rainfall time series in Figure F.16

The soil moisture distribution for Australia for the years corresponding to those of Figure F.17 is shown in Figure F.19. The increased soil moisture for the anomalously wet year 8442, Figure F.19(b), reveals that this increase was primarily confined to the eastern half of Australia, with only a slight increase at Woomera.

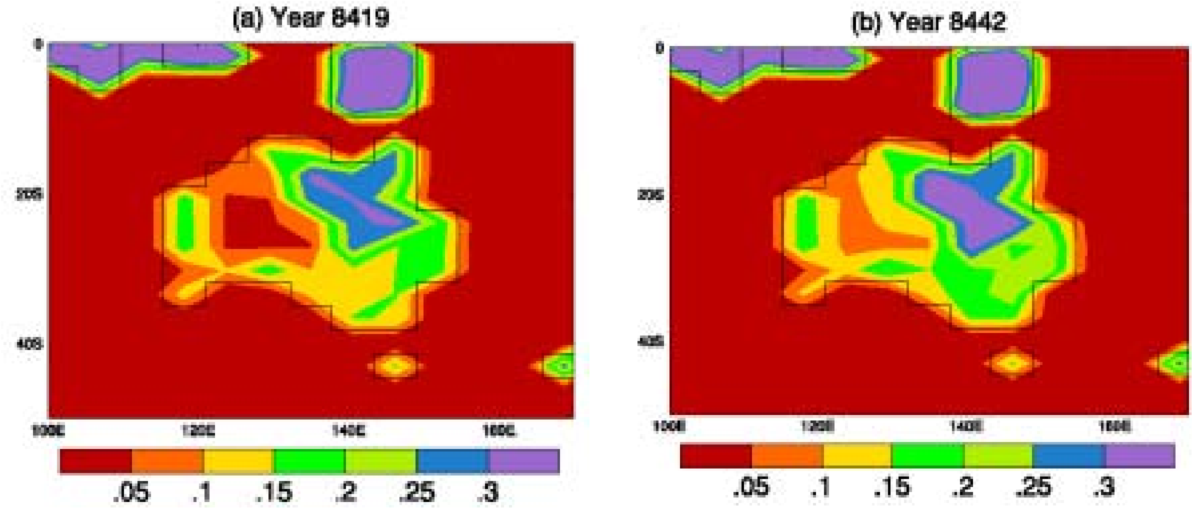

FIGURE F.19
Annual mean moisture content corresponding to the rainfall distributions in Figure F.17
(bar coding is in m^3/m^3)

Finally, comparing peak magnitudes of soil moisture content for the extended greenhouse simulation in Figure F.13 with those in Figure F.18 suggests that greenhouse influences are unlikely to generate anomalous soil moisture values greater than those attributable to present climatic variability.

Since 1000 years of daily data were saved during this 10,000-year simulation it was possible to undertake a more quantitative study of surface wind intensities than was achievable for the above greenhouse runs. The annual mean surface wind intensity at Woomera was very similar in magnitude and variability to that shown previously in Figure F.11. As would be expected, considerably more variability is obtained when daily values are examined. For this purpose, year 4361 was arbitrarily selected for examination.

The time series in Figure F.20 compare the daily zonal (east–west) and meridional (north–south) winds for the lowest model level (≈ 300 m) for year 4361. The figure reveals approximately weekly fluctuations in wind intensities, associated with the passage of synoptic systems, as well as seasonal variations. The strongest winds occurred in winter reaching a magnitude of 15 m/s. Maximum soil erosion attributable to winds would be expected in summer when dry conditions prevail, thus permitting dust to be easily raised. The winds at this time are typically weaker.

The large-scale wind patterns over Australia are shown in Figure F.21 for separate days when peak velocities for the whole year occurred for each wind. The figure indicates that winds in the Woomera region are part of large-scale synoptic patterns, with peak intensities located reasonably close to Woomera. Such large-scale systems are intrinsic characteristics of the climatic system and will continue to prevail under greenhouse conditions.

As indicated in Figure F.11 there is no trend to increasing wind intensities under greenhouse conditions, hence the level of activity shown in Figures F.20 and F.21, which is typical of current conditions, would not be expected to change significantly.

It should be noted that there is some speculation in the scientific literature that more intense storms might occur under greenhouse conditions. This is based on the assumption that typical storms should be more energetic, as the greenhouse climate will permit more latent energy to be contained in the warmer, and therefore moister, atmosphere. Well-documented evidence to support this speculation is currently lacking (but see Intergovernmental Panel on Climate Change (2001)).

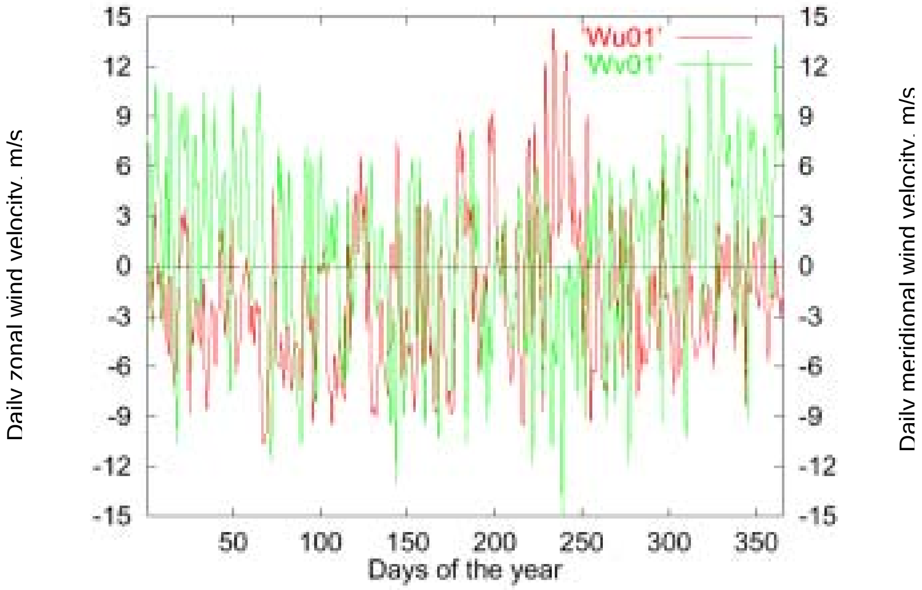

FIGURE F.20
Daily values of the zonal and meridional winds at Woomera for an arbitrarily selected year (4361)

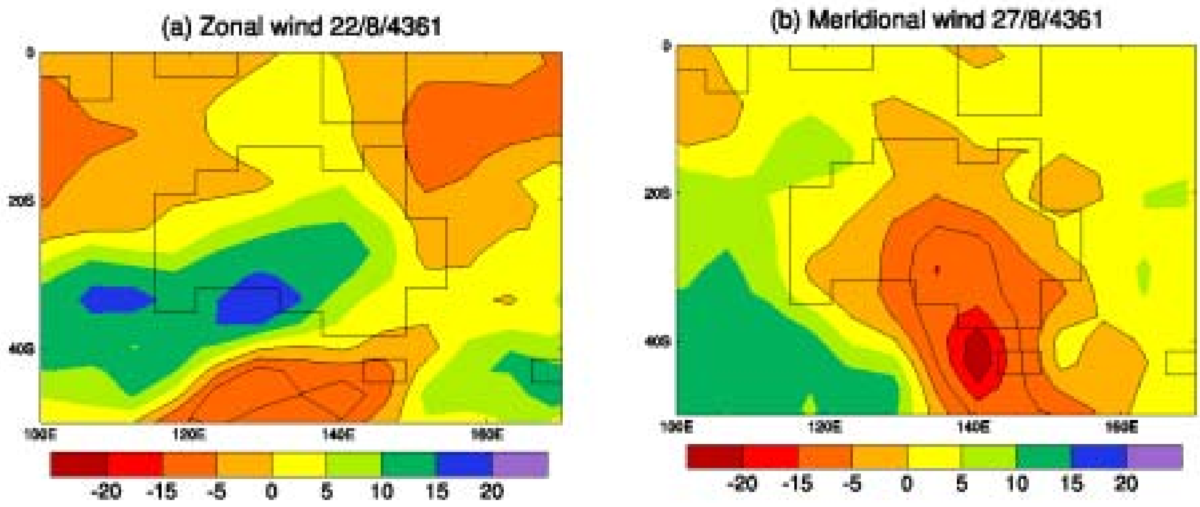

FIGURE F.21
Zonal and meridional wind maxima for Woomera as identified from Figure F.20 (bar coding is in m/s)

F.5 Simulations with the CSIRO Mark 3 model

As noted in the Introduction the Mark 3 model is a considerable improvement on the Mark 2 model. Of particular interest is that the soil moisture formulation in the Mark 3 model has six soil levels, compared with two in the Mark 2 model, and drainage is now explicitly represented. Drainage refers to the transfer of water from the bottom soil layer into the underlying soil and represents subsurface flows to rivers and recharge of aquifers.

To date, two types of simulation have been made with the Mark 3 model. The first uses the atmospheric, sea-ice and biospheric components of the model, with the sea surface temperatures being specified from observations at monthly intervals. Currently, an ensemble of five simulations has been completed for the period 1950 to 1998. By specifying the sea surface temperature the model is 'forced' such that it attempts to replicate the *observed* climatic variability over the period concerned. An ensemble of simulations has been made to allow for the impact of chaos on the climatic system. An ensemble should preferably be used in all simulations, but this constitutes too excessive a computational burden for present computer facilities.

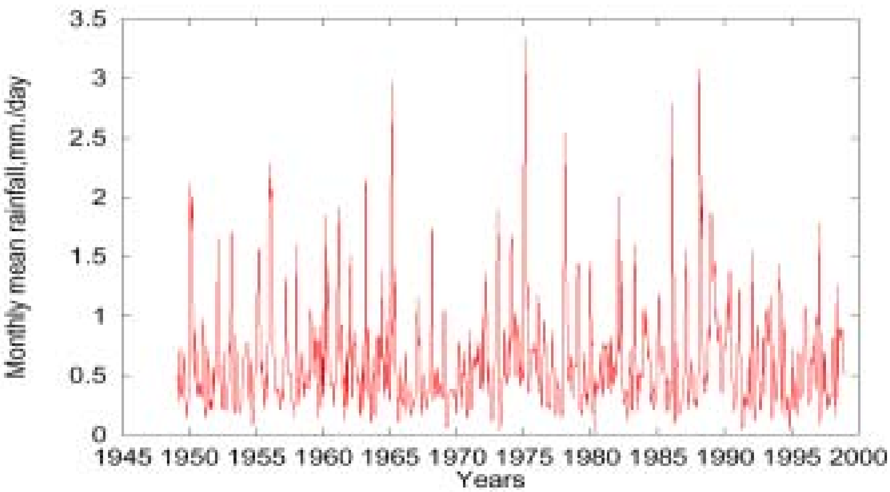

FIGURE F.22
Simulated monthly rainfall for Woomera for the period 1949 to 1998 based on the five-member ensemble mean

The second Mark 3 simulation is a very recently completed greenhouse run using the SRES A2 case and the coupled model, and will be detailed below.

Dealing with the forced runs first, Figure F.22 shows a time series for the Woomera region of rainfall for the period 1949 to 1998. The average of the five ensemble members is illustrated in the figure. Each of the major peaks in Figure F.22 is associated with the occurrence of a La Niña event and enhanced rainfall over much of Australia. The rainfall intensities in this figure are higher than those in the Mark 2 model and are in better overall agreement with observation. The critical feature of the rainfall in this figure is that the overall low rainfall amount is interspersed with heavy rainfall events on a multi-annual basis that are up to three times as intense. Since it is heavy rainfall events that cause soil erosion, any change in the magnitude and frequency under greenhouse conditions needs to be carefully explored. The corresponding soil moisture content averaged over the lower four soil layers (these cover the depth 0.08–4.52 m) is given in Figure F.23. The average of the five ensemble member is illustrated in the figure. Each of the major peaks is associated with the enhanced rainfall in the Woomera area. The time series indicates a range of three in the interannual variability of the soil moisture content, essentially attributable to natural climatic variability. Although not shown here, the intra-ensemble variation of the soil moisture content approached 100% on occasions in this time series.

The soil moisture values in Figure F.23 are less than those for the Mark 2 SRES cases in Figure F.10. This is attributable to the much more realistic formulation used in Mark 3 as well as the soil moisture being averaged over a deeper layer, 4.5 m compared to 0.5 m in Mark 2.

Figure F.24 illustrates the spatial pattern of soil moisture content over Australia for the maximum and minimum values of the time series in Figure F.23. The overall spatial pattern is characteristic of the rainfall distribution (see Figure F.17 for example). The soil moisture contents in Figure F.24 are for a single member of the five member ensemble. The chosen ensemble member had the largest soil moisture values for the two years under consideration, thus the results in the figure effectively represent upper limits, at least for the Woomera region. The figure clearly shows how small the changes in the spatial pattern of soil moisture in the Woomera region are compared to the magnitude of the temporal changes in Figure F.23. This is a consequence of the high spatial gradient of soil moisture content over southern Australia.

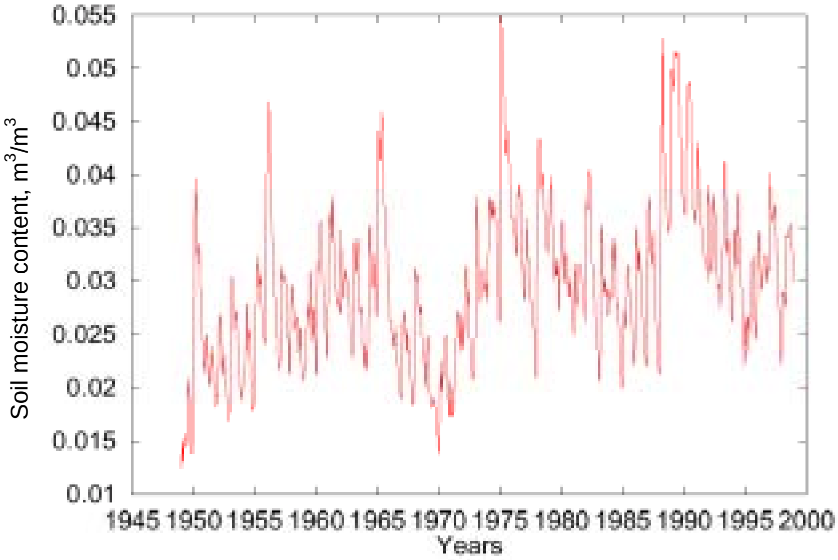

FIGURE F.23
Simulated monthly soil moisture content for Woomera for the period 1949 to 1998 based on the five-member ensemble mean

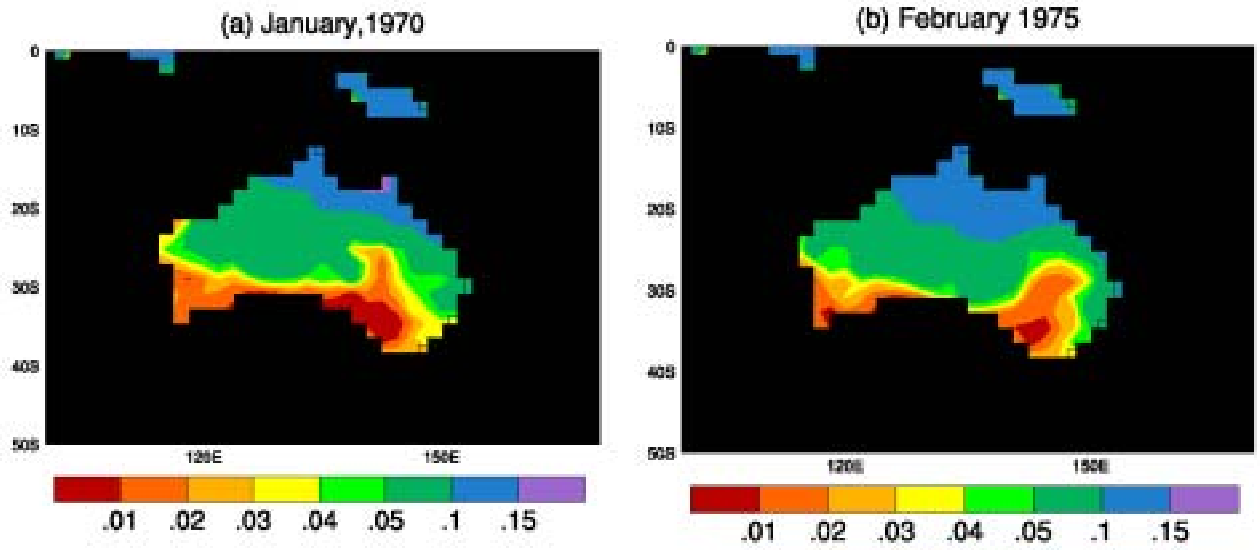

FIGURE F.24
Soil moisture content for the most extreme dry month (left) and extreme wet month (right) for Woomera (bar coding is in m^3/m^3)

The drainage of water from the lowest soil moisture layer was found to be zero over the timeframe 1949 to 1998 across all five ensemble members for Woomera. This outcome is attributable to the low soil moisture content and rainfall rates which prevailed.

Figure F.25 illustrates the mean drainage over Australia for the period 1967 to 1997 to provide an indication of the overall climatology (no corresponding observations are available). The similarity between the soil moisture values in Figure F.24 and the drainage in Figure F.25 is readily apparent. Comparison of observed runoff to simulated *surface* runoff and drainage indicates that most of the drainage in the model must go to river runoff. A small component remains for recharge of aquifers. To the extent that this representation in the model is correct, this implies that contamination of groundwater supplies by any deep percolating water coming in contact with the disposal facility would be expected to be minor. Figure 25 highlights the hydrologic stability, in the sense of long term, prevailing aridity, over southern Australia and NSW.

The greenhouse simulation with the Mark 3 model used the SRES A2 case (see Figure F.4), the fastest growing CO_2 scenario. The simulation commenced in 1960 and attained an equivalent $2\times CO_2$ atmospheric concentration in 2069 AD. Only a single greenhouse simulation has been possible to date with the Mark 3 model.

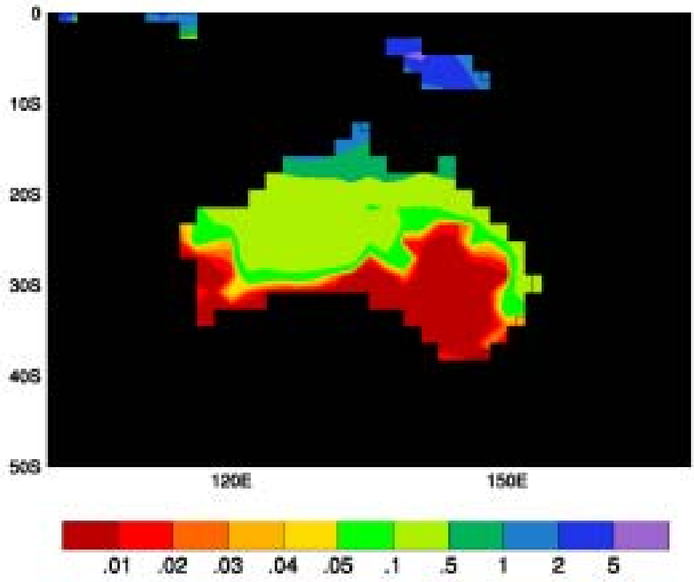

FIGURE F.25
Drainage rate of soil moisture based on the five member ensemble mean and averaged over annual mean values for years 1967 to 1997 AD. Colour bar coding is in mm/day

The rainfall time series for Woomera for this simulation is given in Figure F.26. In general, the Mark 3 model produced higher rainfall amounts than Mark 2 (but note *annual* mean values are shown for the Mark 2 model in Figure F.9, compared with *monthly* values in Figure F.26). Part of this discrepancy is due to the finer horizontal resolution of Mark 3, but this model currently generates somewhat too much rainfall over Australia compared with observations. The corresponding Mark 3 soil moisture content and drainage rate time series for Woomera (Figure F.27), highlight the correspondence between the three time series. Compared to the 'climatological' soil moisture values in Figure F.23 the mean values in Figure F.27 are almost doubled (attributable to the higher rainfall in Figure F.26), but they are still smaller than the Mark 2 SRES values in Figure F.10. As mentioned above this difference is due to the different soil moisture formulations used in each model version, with that in the Mark 3 model being considered to be more realistic.

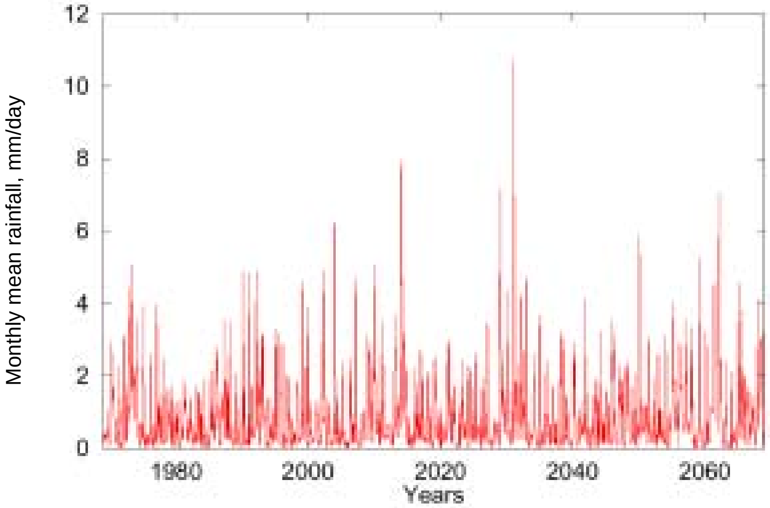

FIGURE F.26
Monthly mean rainfall for Woomera from the Mark 3 greenhouse simulation

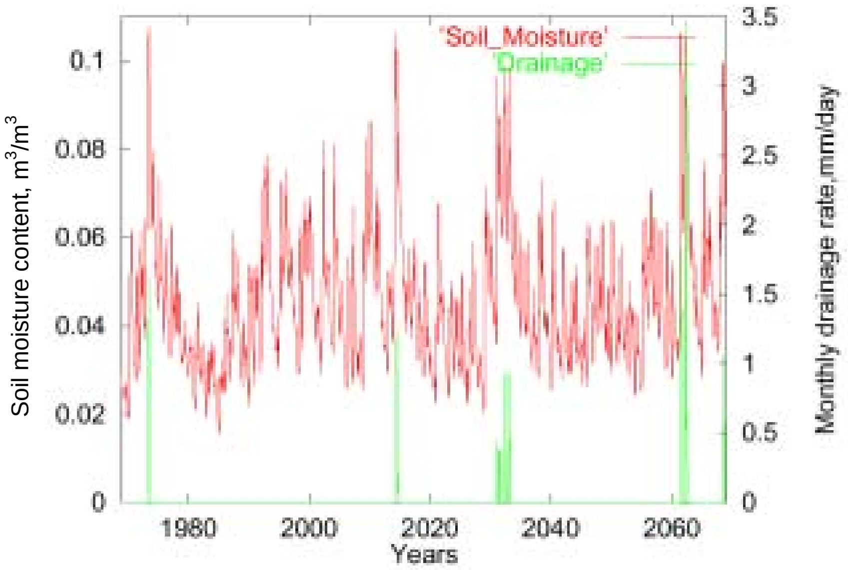

FIGURE F.27
Monthly mean soil moisture content and drainage rate for Woomera from the Mark 3 greenhouse simulation

Interestingly, this Mark 3 greenhouse simulation generated sufficiently high soil moisture values on a number of occasions to permit drainage to occur to the underlying soil. A point to note in regard to the soil moisture and drainage values, is that it is not just the peak rainfall amounts that are important in generating these values, but also the precedent rainfall as this builds up the soil moisture content.

The Australia-wide rainfall distribution for the peak rainfall amount in Figure F.26 was compared to that for a very dry sequence of years about 10 years earlier. The corresponding rainfall distributions are shown in Figure F.28 and provide an indication of the range of variability occurring. According to this figure the low rainfall at Woomera, which is broadly typical of the climatology, is associated with a NW–SE dominant rainband to the north of Woomera. The peak rainfall occurrence at Woomera, Figure F.28(b), resulted from this rainfall band migrating southwards. Clearly this is an unusual event as indicated by the time series in Figure F.26.

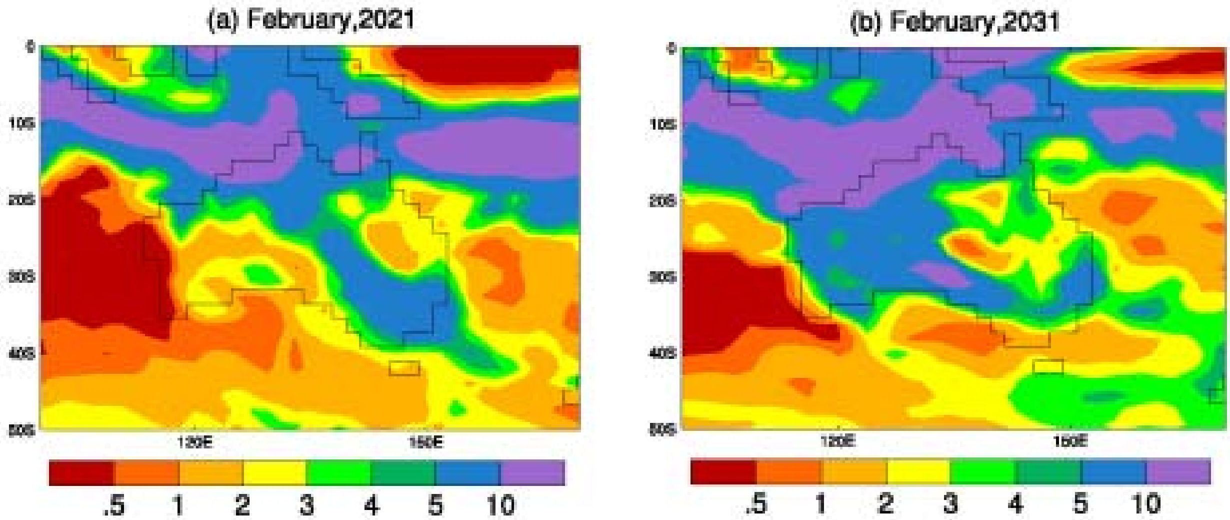

FIGURE F.28
Monthly mean rainfall distributions over Australia from the Mark 3 greenhouse simulation for a typical situation (left) and for a peak rainfall year (right) (bar coding is in mm/day)

An alternative perspective of the greenhouse-induced hydrologic changes is provided by the Australia-wide distributions of rainfall and soil moisture differences in Figures F.29 and F.30 respectively. These show differences between 30-year means for the start and end of the simulation. A slight rainfall increase is indicated for much of Australia, in broad agreement with Figure F.8 and the top panel of Figure F.14. A corresponding increase in soil moisture, *although of very small magnitude*, is shown in Figure F.30.

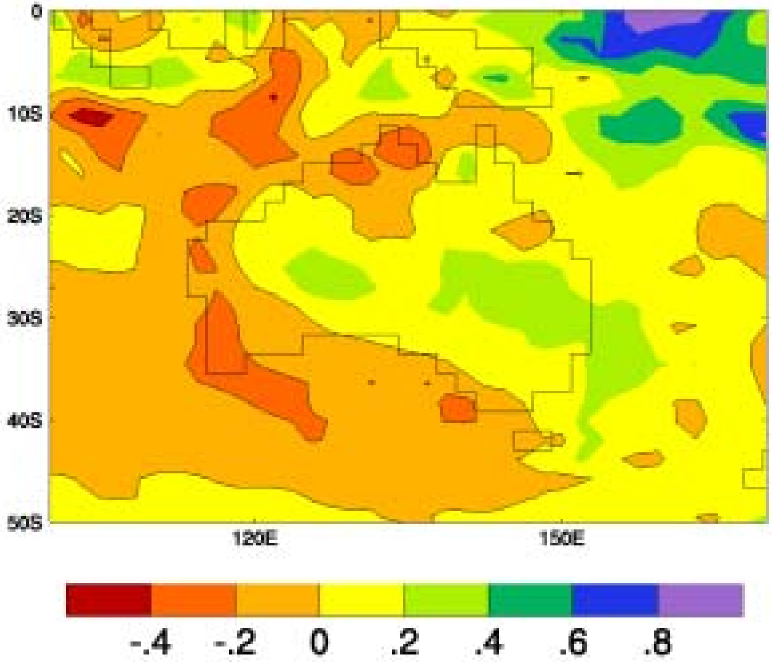

FIGURE F.29
Rainfall anomalies from the Mark 3 greenhouse simulation defined as the difference between the annual means of years 2040 to 2069 AD minus the annual means of years 1961 to 1990 AD (bar coding is in mm/day)

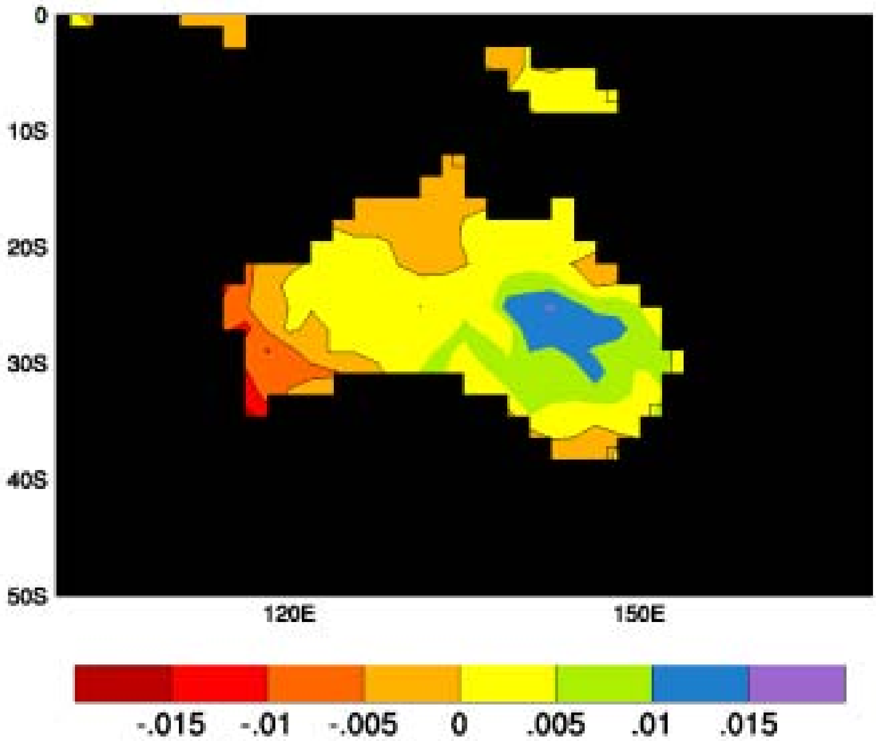

FIGURE F.30
Soil moisture content anomalies from the Mark 3 greenhouse simulation 2069 AD minus the annual means of years 1961 to 1990 AD (bar coding is in m^3/m^3)

The overall impression from the Mark 3 simulation is again for relatively stable climatic conditions at Woomera under greenhouse conditions, but with occasional *months* where very much above average rainfall might be expected. This issue is addressed again in the next section.

F.6 Greenhouse Simulation with the DARLAM Model

CSIRO has developed a regional model known as DARLAM (Division of Atmospheric Research Limited Area Model) which permits higher horizontal resolution simulations to be made over a restricted region compared to that possible with a global model. Simulations with DARLAM are made via a two-stage process. The first stage involves running out the global model for the greenhouse scenario of interest. The second stage then uses output fields from the global model to ‘force’ DARLAM for the specified region over the timeframe of interest. In general, DARLAM produces improved climatic simulations, as demonstrated by studies for present climatic conditions. The improvements result from the finer horizontal resolution, which permits a more accurate replication of physical processes in the model, together with a better representation of orographic features. To date DARLAM simulations have only been forced with outputs from the CSIRO Mark 2 coupled model.

The greenhouse scenario used for the present DARLAM run used equivalent CO_2 concentrations corresponding to the IS92a scenario, the same scenario as used in the simulation in Section F.3. The DARLAM simulation was run over an extended ‘Australian region’ (see Figure F.31), for the period 1960 to 2100 AD.

The rainfall anomalies corresponding to this time period for the Australian region are given in Figure F.31. In agreement with the other simulations presented above increased rainfall is indicated over much of Australia for annual mean conditions. This result is closest to the A2 SRES case in Figure F.8, for which the IS92A CO_2 concentrations are most similar, although no aerosols were included in the DARLAM simulation or its parent GCM simulation.

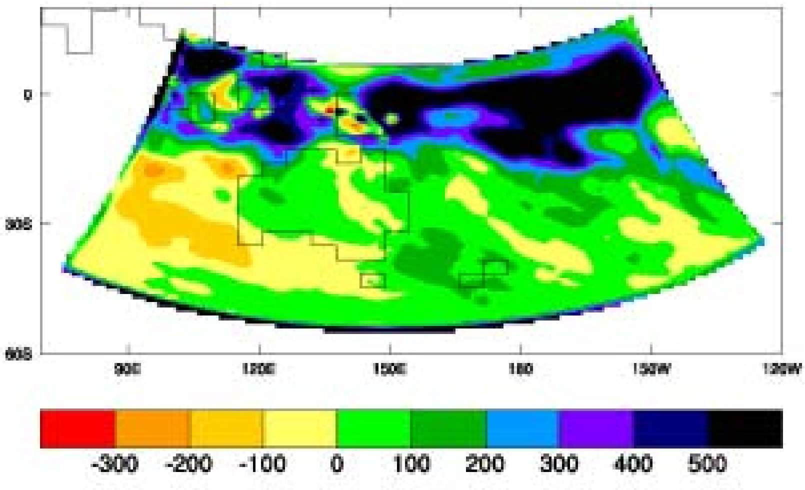

FIGURE F.31
Rainfall anomalies from the DARLAM model defined as the difference between the annual means of years 2070 to 2099 AD minus the annual means of years 1960 to 1990 AD (bar coding is in mm/30 years)

The temporal variation of greenhouse-induced rainfall changes for Woomera for the period 1960 to 2100 AD from the DARLAM simulation is given in Figure F.32. The rainfall intensities in this figure are closer to those of the Mark 3 simulation in Figure F.26 than those for the Mark 2 model in Figure F.9. This is a consequence of the finer horizontal scales used in both the DARLAM and Mark 3 models, as this permits the rainfall producing systems to be simulated more accurately. Figure F.32 reveals a rather stable situation when considering the annual mean values in the figure. However, considerable monthly variability occurred. This figure illustrates a point only partially apparent in the other rainfall time series for the Mark 2 and Mark 3 models. This is the increase in magnitude of the extreme events as the greenhouse simulation progressed. This is now accepted as a robust feature of greenhouse simulations and is also apparent in recent observed rainfall time series. Thus, an increase in rainfall *intensity* may occur under enhanced greenhouse conditions, even though the annual mean rainfall is time invariant (see Figure F.32). This feature results in an approximate halving of the return period for a given rainfall intensity, with the possibility that previously unobserved, intense rainfall rates might occur, see Hunt and Elliott (2001) for a detailed analysis for Maralinga.

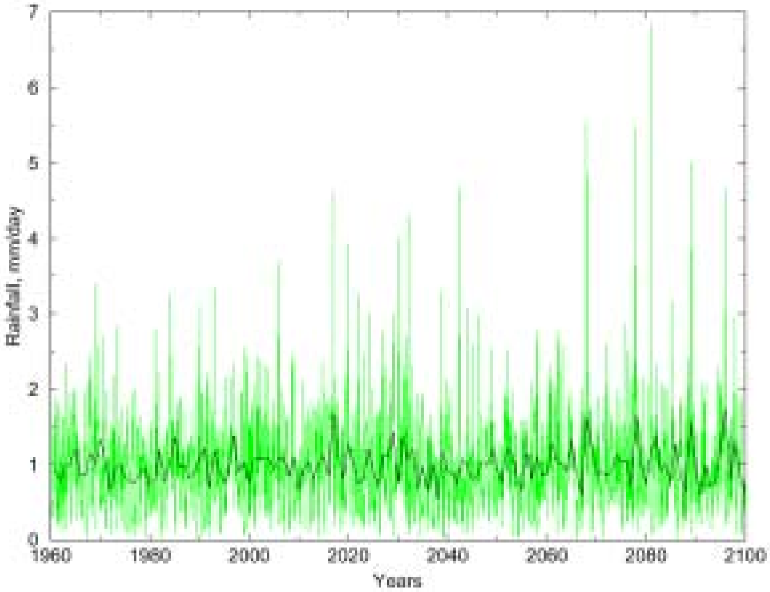

FIGURE F.32
Monthly mean rainfall for Woomera from the DARLAM simulation (black line represents the annual mean)

Assuming that the disposal facility is designed to cope with the present maximum observed rainfall intensity, then an increase in the *frequency* of such events should create no problems. However, this might not be the case if the maximum *intensity* were to increase.

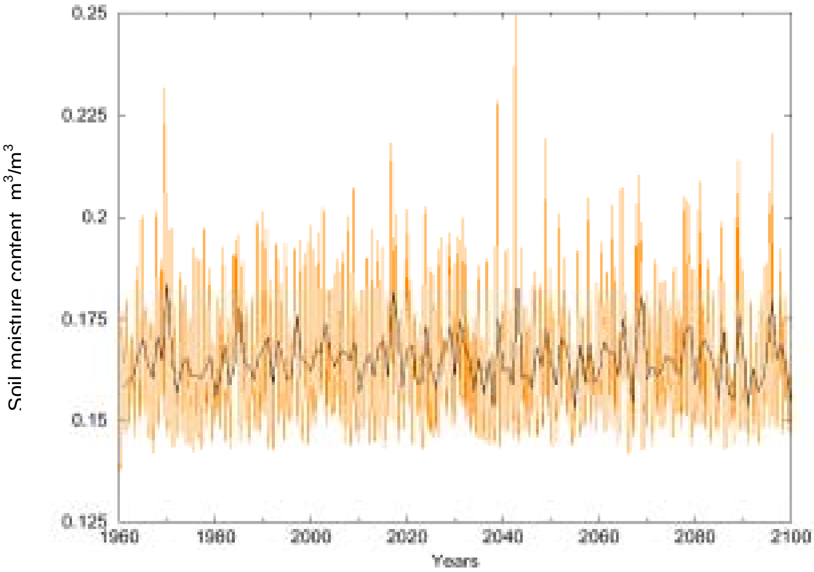

FIGURE F.33
Monthly mean soil moisture content for Woomera from the DARLAM simulation (black line represents annual mean)

The time series of DARLAM soil moisture content is illustrated in Figure F.33. While the annual mean exhibits no long term trend, some extreme events occur. (Again, the DARLAM soil moisture content is higher than that in the Mark 3 model as the same formulation was used as in the Mark 2 model.)

Finally, the surface temperature time series for Woomera from DARLAM is given in Figure F.34. A comparable temperature increase to that displayed in Figure F.6 for the SRES cases was achieved. While a large seasonal range is apparent in the figure, the interannual variation of the surface (screen) temperature is somewhat reduced compared with that for rainfall and soil moisture content.

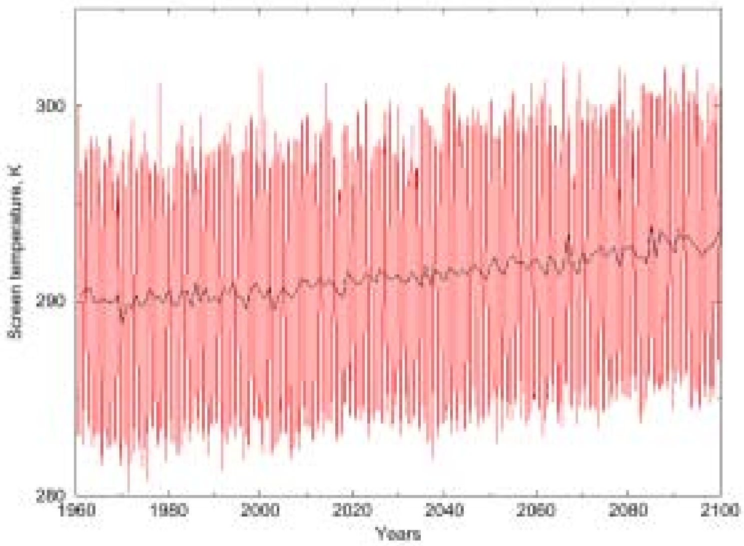

FIGURE F.34
Monthly mean screen temperature for Woomera from the DARLAM simulation (black line represents annual mean)

F.7 Assessment of Possible Climatic Changes over the Next 10,000 Years

This is an extremely difficult task because of the possibility of unexpected events, such as a collision of a comet with Earth, or massive earthquake activity which might destroy the Isthmus of Panama and thus permit the Pacific and Atlantic oceans to link up. Consequently, this assessment will be restricted to possible climatic impacts attributable to present and ongoing drivers of climatic change, additional to the greenhouse-induced changes and natural climatic variability discussed above.

The drivers considered are volcanic activity, solar fluctuations and climatic perturbations associated with orbital variations of the Earth, the so-called Milankovitch effect. Of these, only the last is practically quantified.

The Earth has a history of violent volcanic activity that has had marked climatic impacts. These impacts result from the ejection of volcanic debris with sufficient force for the debris to reach the stratosphere (10–16 km altitude). Stratospheric debris has a lifetime of two or more years and affects climate by reflecting incoming solar radiation and thus cooling the surface. The most influential volcanoes are those in the tropics, as they directly impact on a region that is the heat engine of the climatic system.

Certainly, volcanic activity has declined in intensity over the past few million years. This decline in activity appears to be continuing into the present. For example, over the past two centuries the most violent volcanic eruption was that of Tambora in Indonesia in 1815. This is known as the year without a summer because of the devastating impact of the volcanic debris on the climate. This produced cold and wet conditions over much of the northern hemisphere in 1815 and 1816. The eruption of Krakatoa in Indonesia in 1883 was also an event with global consequences, but much less marked than those of Tambora. In the last few decades there have been major eruptions of Mt Agung and Mt Pinutubo, both smaller than Krakatoa, but these produced relatively small climatic impacts outside of their immediate local zones.

The present quiescent situation as regards volcanic activity is presumably associated with the epochal-length cooling of the Earth, and on this basis might be expected to continue into the future. However, tectonic activity resulting from the continual movement of the Earth's plates could trigger a major onset of volcanic activity.

Overall, any future volcanic activity at current levels will be expected to produce a transient (≈ 2 year) impact on climate in the Woomera area, with a short term counteraction of greenhouse-induced warming.

There are a number of solar fluctuations that can affect climate. Neglecting the aeon-scale solar brightening, which would have a negligible influence over the next 10,000 years, these solar fluctuations are associated with the ≈11-year solar cycle, sporadic influences associated with solar flares and related impulsive outbursts, and possible millennial timescale variations in solar output.

Over the solar cycle the sun's output varies by about 0.1%, which is too small to have any discernible influence on the climate. In any case, the climatic response to such solar variability is very similar to that induced by the greenhouse effect, hence the climatic changes documented above would largely encompass such a solar effect.

There have been a number of attempts to quantify solar variability over the past millennium, with somewhat inconsistent results. Past climatic perturbations, such as the Little Ice Age (1500-1800), have been attributed to solar variability. Note though, that the existence of the Little Ice Age in reality has also been challenged (Jones and Bradley 1995). In any case natural climatic variability appears to be able to explain much of observed climatic perturbations on this timescale (Hunt 1998). Hence, it appears unlikely that such solar variability has produced substantial climatic impacts. Presumably this situation should prevail into the near future.

A more difficult solar effect to assess is that associated with solar flares and other similar perturbations. Such events are known to influence the upper atmosphere, as evidenced by aurorae and disturbances to radio communications. Very strong flares can also damage electricity supplies. Climatic impacts associated with these phenomena are presumed to be indirect, such as cosmic rays destroying stratospheric ozone by production of nitrogen ions or producing nuclei for cloud formation. The subject is difficult to quantify as regards climatic impacts and remains controversial. Since such solar events have lifetimes of a few days at most it is unlikely that any persistent climatic impacts are produced. In any case, their major area of influence is in the polar regions.

There is no reason to assume that solar activity will change over the next 10,000 years, hence any solar-induced climatic perturbations should not be outside present limits. See Shindell et al. (2001) for a discussion of simulations related to the above affects.

There is a large body of literature associated with climatic perturbations attributable to variations in the Earth's orbital path around the sun, the Milankovitch effect. This effect has been primarily linked to the occurrence of ice ages and interglacials. The principal periodicities associated with the Milankovitch effect are 20,000, 40,000 and 100,000 years, and there are distinct observational studies identifying the former two periodicities with past ice ages. Clearly this process is a major driver of climatic variability.

The Earth's orbital values can be calculated with considerable accuracy over a time span of 1,000,000 years. Projections into the future indicate, based on what appears to be the best available model, 'an exceptionally long interglacial lasting 50,000 years' (Loutre and Berger 2000). This implies that no major climatic perturbations attributable to the Milankovitch effect, such as an ice age, are likely to emerge over this timeframe. In this sense the present climate would represent the status quo over this extended period.

Assuming that the present interglacial does persist for the next 50,000 years a major uncertainty still exists regarding the magnitude of climatic perturbations associated with natural climatic variability. Precisely what is the possible amplitude, duration and regional extent of such variability is currently unknown, although Section 4 indicates typical ranges of activity. Multi-decadal periods of *overall* drought or pluvial conditions can occur; a good example is the current 30-year dry episode impacting southwest Western Australia. Of more relevance was the occurrence of persistent above average rainfall in the region south of Woomera in the late 1800s, which resulted in an extension of agriculture into that area.

Such a change is possible in the future, but given the nature of rainfall variability these situations are chaotically determined and thus cannot be predicted, only statistical assessments are possible.

A further factor of concern over this timeframe is the melting or collapse of the polar icesheets. A complete melting of these icesheets would raise sea-level by about 70 m, which would cause world-wide catastrophes. In addition, substantial changes would result to oceanic circulations with consequent (unknown) impacts on climate. The melting of these ice sheets would require temperature rises of 3 K or more to be sustained for millennia. This situation is discussed in Intergovernmental Panel on Climate Change (2001), but no probabilities of its likelihood are given. Under these circumstances it is only possible to flag this climatic perturbation.

F.8 Concluding Remarks

A wide-ranging assessment has been provided of the possible range of future climatic changes in the Woomera region, particularly emphasising those climatic variables relevant to the proposed radioactive waste disposal facility. Because the future atmospheric concentrations of radiatively active gases (primarily CO_2 in the present context) are unknown, climatic changes have been presented for a number of possible scenarios. The basic outcomes are as follows:

With a high level of confidence it can be stated that a trend towards higher surface temperature will prevail in the future owing to the enhanced greenhouse effect. Interannual fluctuations in temperature will be superimposed upon this rising trend. A surface temperature increase in the order of 4 K is possible by the end of this century.

At the lower level of confidence a small rainfall increase is indicated in the Mark 3 and DARLAM models for the Woomera area attributable to the greenhouse effect. Quite marked interannual variability of rainfall is exhibited in all the results. While substantial variations in the intensity of annual mean rainfall exists under present conditions, as shown in the simulations in Section F.4, there may be a slight increase in maximum intensities under greenhouse conditions. This is most noticeable in the DARLAM model.

A variety of analyses made with the CSIRO and other models indicates a possible increase in the frequency of more intense rainfall under greenhouse conditions. For a given rainfall intensity there is typically a halving of the return period. Thus the impact of the more extreme rainfall intensities can be expected to become more critical. Such extremes occur as intense rainfall over a period of one or two days.

Thus there is a possibility for an increase in rain-induced soil erosion events at Woomera from the present very low levels of erosion.

Soil moisture does not exhibit any sign of an increasing trend, apart from a very small increase in the Mark 3 greenhouse simulation, indicating a continuation of the present marginal vegetative cover. Given the expected temperature increase this vegetative cover could become even sparser. The interannual variability of the soil moisture content under greenhouse conditions should be similar to that prevailing currently.

Given the aridity of the Woomera region the possibility exists for a change in wind-induced soil erosion under greenhouse conditions. Since the soil moisture content is expected to remain similar to present any increase in such erosion would be wind-related. There appears to be no trend for increased surface wind velocities in the Woomera region for annual mean conditions. This is presumed to indicate that there are no exceptional increases in daily wind intensities. Compared to annual mean wind intensities in the order of 6–7 m/s, daily intensities were shown to range up to 15 m/s and can be related to well-defined synoptic systems. Currently wind erosion does occur in the Woomera region, depending on suitable synoptic conditions, but no increase in such erosion appears likely under greenhouse conditions.

Finally, when the timeframe of this study is extended out to 10,000 years, there appears to be no reason to assume that there will be substantial changes, compared to past history, in external forcing mechanisms of climatic variation such as solar perturbations, volcanic eruptions or changes in Earth's orbital properties. A more critical unknown, currently unquantifiable, is the possible melting of the polar ice sheets by the greenhouse effect, with consequent impacts on sea-level, oceanic circulations and climate. There does exist some non-deterministic possibility for changes induced by natural climatic variability, as have occurred in the past and are occurring at present, but it is unlikely that they would be sufficient to affect the viability of the proposed disposal facility.

Nevertheless, the overall conclusion is that future climatic change or climatic variability would appear to represent a minor factor in the long term security of a Woomera-based radioactive disposal facility.

F.9 References

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APPENDIX G

Appendix G

ORGANISATIONS CONSULTED

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Appendix G
Organisations Consulted

This appendix lists the organisations consulted in the preparation of this draft environmental impact statement.

G.1 Introduction

The Commonwealth has undertaken an extensive consultation program both during the siting studies for the national repository, and associated with the preparation of the draft environmental impact statement (Draft EIS).

A number of committees and informal groups serve as forums for the exchange of information between the proponent (the Department of Education, Science and Training (DEST)) and stakeholders, including community groups, and Commonwealth and State government officials. The committees were established to ensure that the views of stakeholders are taken into account in decision making. The committees are:

- Regional Consultative Committee (RCC): members include representatives of local government, industry, pastoralists, and Aboriginal groups
- South Australian Government Consultative Committee: members include officials from South Australian Government departments and agencies
- Commonwealth Inter-departmental Committee: members include officials from Commonwealth government agencies
- Commonwealth–State Consultative Committee on Radioactive Waste Management.

Details about consultation during the site selection process can be found in Section 1.5.3 of the main report of this EIS.

G.2 Organisations Consulted

G.2.1 Regional Consultative Committee meetings

The RCC consists of key regional stakeholders including pastoralists, Aboriginal groups, and representatives from local government and industry.

Eight RCC meetings have been held, at the start and conclusion of each part of the project including two held on the draft EIS, one on 1 May 2001 in Woomera and the other on 31 July in Roxby Downs.

At these meetings, the committee was kept informed on issues associated with the repository, including:

- the environmental impact assessment/statement process including the EIS Guidelines, field protocol for the planned flora and fauna, geomorphological and other field investigations, and the associated timeframes (at Roxby Downs on 31 July 2001)
- the Draft EIS methodology and studies (Vic Farrington, PPK, and Dr Bob Anderson, Halliburton KBR).

G.2.2 Consultation with Pastoralists

The Draft EIS methodology and studies, including the field protocol for the planned flora and fauna, geomorphological and other field investigations, were described at a meeting at Roxby Downs on 30 July 2001.

G.2.3 South Australian Government Consultative Committee

This committee was established to facilitate consultation between the South Australian and Commonwealth governments. It is an advisory committee on matters associated with the proposed national repository, with no decision-making power. The forum is open to representation by all South Australian Government departments and agencies with an interest in the repository.

Meetings with South Australian government representatives took place on 17 February, 17 April and 2 July in 1998; 21 October in 1999, 9 August and 7 November in 2000 and 30 April and 30 July in 2001.

The meeting on 30 July 2001 (held in Adelaide) described the Draft EIS methodology and studies.

G.2.4 Commonwealth Interdepartmental Committee

This committee comprises representatives from Commonwealth departments of Defence, Prime Minister and Cabinet, Industry, Science and Resources, Environment and Heritage, Attorney-General's (Native Title Division), and the Bureau of Rural Sciences, Aboriginal and Torres Strait Islander Commission (ATSIC), the Australian Nuclear Science and Technology Organisation (ANSTO), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

The IDC was established in October 1997 to facilitate cooperation between Commonwealth agencies on radioactive waste management operational and policy matters, particularly for the national repository project. Meetings were held on 9 October 1997; 27 April 1998; 26 October 1999; 6 November and 4 August in 2000; 24 April and 17 August in 2001. The meeting on 17 August (held in Canberra) described the Draft EIS methodology and studies.

G.2.5 Commonwealth/State Consultative Committee on Radioactive Waste Management

A Commonwealth/State Consultative Committee on Radioactive Waste Management was established in 1980, to consider (among other issues) the safe management of radioactive waste in Australia, and has met regularly since that time. The committee considered how the siting of a national repository for Australia's low level and short-lived intermediate level radioactive waste should be progressed. In response to recommendations arising out of an inquiry into Australia's role in the nuclear fuel cycle by the Australian Science and Technology Council, in 1985, the committee recommended a national program to identify potentially suitable sites for a national near-surface repository.

The Committee has been regularly briefed on the progress of the national repository project, and the national store project for intermediate level radioactive waste.

Matters concerning the inventory of radioactive waste held by Commonwealth agencies and states and territories have been discussed by the committee, and regular updates on holdings were requested by the proponent.

G.2.6 Direct Consultation with Commonwealth and State Agencies during the Site Selection Process

The Commonwealth has undertaken extensive consultation with the Department of Defence since February 1998, when the central–north region of South Australia was selected for siting studies for the repository. Issues discussed included information on the current and planned use of the Woomera Prohibited Area and the Nurrungar Prohibited Area and relevant information was provided. The proponent indicated that Defence's views would being given due consideration throughout the siting and the EIS process. Defence's assistance was also sought on information concerning their inventory of low level and short-lived intermediate level radioactive waste, and this information was provided.

Environment Australia has been consulted on matters associated with the environmental assessment process before the project was referred for assessment under the *Environment Protection and Biodiversity Conservation Act 1999*, and on matters associated with the EIS.

ARPANSA was consulted on matters associated with the timing of application for licences for the siting, construction and operation of the facility.

The South Australian departments of Primary Industries, Transport, and State Aboriginal Affairs were consulted on matters relating to the repository, both directly as well as through committee forums. Primary Industries and Resources SA was particularly consulted by the Bureau of Rural Sciences on matters associated with the geology and groundwater of the region, and the procedure for drilling investigative holes. The Department of Transport provided advice on public and private roads in the State, and practices for road maintenance. The Department of State Aboriginal Affairs provided information on matters relating to Aboriginal heritage issues. ATSIC also provided some relevant advice.

PPK, the Commonwealth's contract manager for the EIS process, liaised directly with Transport SA, and with the SA Department for Environment and Heritage on environmental matters.

All state/territory radiation safety regulators (associated with various departments of health, or environment) were consulted on the matter of the radioactive waste inventories in their respective jurisdictions.

G.2.7 Additional Organisations Consulted During EIS

The following organisations have also been consulted on specific aspects of the project during the preparation of this EIS.

- Bureau of Rural Sciences
- Australian Radiation and Nuclear Safety Agency
- SA Department of Human Services (Radiation Section)
- ACT Department of Health and Community Care (Radiation Safety Section)
- NSW Environment Protection Authority (Radiation Control Section)
- Territory Health Services (Radiation Health Branch)
- Tasmanian Department of Community and Health Services (Health Physics Branch)
- Victorian Department of Human Services (Radiation Safety Unit)
- Queensland Department of Health (Radiation Health Branch)
- SA Country Fire Service
- SA Metropolitan Fire Service
- Transport SA
- Road and Traffic Authority of NSW
- Northern Territory Department of Transport and Works
- Tasmanian Department of Infrastructure, Energy and Resources
- Queensland Department of Main Roads
- Vicroads, Victoria
- WMC Ltd
- Department of Defence

- Geoff Williams, Lynette Higgins, ARPANSA
- Dr Henk Heinje, Dr Andrew Jenkinson, ANSTO
- David Jackson, Francis Knight, Environment Australia
- Dr Bob Inns, Robert Brandle, Peter Canty, Nick Neagle, Jennie Rodrigues, Department of Environment and Heritage
- Vlad Potezny, State Aboriginal Affairs,
- Dr Graham Bell, Plant Biodiversity Centre, Department of Environment and Heritage
- Maya Penck, Mark Hutchinson, South Australian Museum
- Andrew Starkey, Bob McKenzie, Defence, Corporate Services and Infrastructure Group, Defence Support Centre Woomera
- Mark Donaghey, Defence Corporate Services & Infrastructure Centre - SA
- Brendan Lay, Pastoral Board
- Bureau of Meteorology - Woomera
- David and Cathy Oag, Arcoona Station
- Michael Wilkinson, Wirraminna Station
- Danny and Janet Oldfield, Andamooka Station

APPENDIX H

Appendix H

STUDY TEAM

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Appendix H
Study Team

Name	Organisation	Project role
Project Management and Integration		
Dr David Cruickshanks-Boyd	PPK Environment & Infrastructure	Project Director
Vic Farrington	PPK Environment & Infrastructure	Project Manager
Hannah Ellyard	PPK Environment & Infrastructure	Project Coordinator
Dr Robert Anderson	Halliburton KBR	Team Leader Environment, Social and Planning
Rolfe Hartley	Halliburton KBR	Client Integration Manager, Canberra
James Corbett	PPK Environment & Infrastructure	Contract Management
EIS Compilation and Environment Assessment		
Dr Mark Shepherd	ATA Environmental	Repository operations and management
Gordon Benham	PPK Environment & Infrastructure	Transport
Dr Peter Woods	PPK Environment & Infrastructure	Geology, hydrology and hydrogeology
Melanie Pierini	PPK Environment & Infrastructure	Geology
Alex Eadie	PPK Environment & Infrastructure	Repository concept design
Dr Peter Mitchell	PPK Environment & Infrastructure	Slope stability
Gary Hirst	PPK Environment & Infrastructure	Repository seepage modelling
Ian Potts	PPK Environment & Infrastructure	Unsaturated zone seepage modelling
Cindy Tomamichel	PPK Environment & Infrastructure	Seepage modelling
Stuart Mathews	PPK Environment & Infrastructure	Hydrogeology field investigations
Ashley Taylor	PPK Environment & Infrastructure	Hydrogeology field investigations
Dr Robert Anderson	Halliburton KBR	Fauna survey and assessment
Frank Badman	Badman Environmental	Vegetation survey and flora assessment
Cathy Pryde	Halliburton KBR	Biologist
Katherine Barr	Halliburton KBR	Biologist
Sarah Reachill	Halliburton KBR	Field and GIS assistant
Ray Grosser	Halliburton KBR	Field assistant
Terry Reardon	SA Museum	Biologist (bats)
David Hirst	SA Museum	Biologist (spiders)
Archie McArthur	SA Museum	Biologist (ants)
Dr John Read	Ecological Horizons	Technical review
Simone Fogarty	Halliburton KBR	Planning and social assessment
Scott Haynes	Halliburton KBR	Planner
Rolfe Hartley	Halliburton KBR	Defence activities assessment
Georgina Legoe	Halliburton KBR	Halliburton technical review
Suzanne Roberts	Halliburton KBR	Project secretary
Dr Philip Hughes	Huonbrook Environment and Heritage	Geomorphology and Aboriginal archaeology
John Waters	On Site Technology	Air quality monitoring
Dr Malcolm Cooper	Envirorad Services Pty Ltd	Radiation regulatory and assessment review
Mark Sonter	Radiological Consultant	Radiation risk review

Name	Organisation	Project role
Vic Farrington	PPK Environment & Infrastructure	EIS compilation
Hannah Ellyard	PPK Environment & Infrastructure	EIS compilation
Rontheo van Zyl	PPK Environment & Infrastructure	EIS compilation
Andrew Larwood	PPK Environment & Infrastructure	EIS compilation
Radiological Assessment		
Dr Jane Smith-Briggs	RWE Nukem Ltd	Team leader
Martin Kelly	Serco Assurance	Risk assessment
Dave Wells	RWE Nukem Ltd	Inventory
Tommy Green	RWE Nukem Ltd	Waste acceptance criteria
Alistair Barclay	RWE Nukem Ltd	Inventory
Rebecca Ferris	RWE Nukem Ltd	Inventory
Mike Thorne	Mike Thorne Associates Ltd	Transfer factors/climate change review
Owen Chaldecott	Serco Assurance	Transport issues
Richard Cummings	Serco Assurance	Gas/groundwater assessment
Report Production		
Kathie Stove	in writing	Editor
Jo Mason	Mason Edit	Editor
Ashwood Caesar	PPK Environment & Infrastructure	GIS map production
Chris Rudd	PPK Environment & Infrastructure	GIS map production
Gail McCartney	PPK Environment & Infrastructure	Graphic design
Kate Ahern	PPK Environment & Infrastructure	Report production
Carolyn Kroon	Halliburton KBR	GIS map production
Kym Ralph	Halliburton KBR	GIS map production
Sue Johnson	PPK Environment & Infrastructure	Word processing