RADIUM HILL URANIUM MINE & LOW-LEVEL RADIOACTIVE WASTE REPOSITORY

MANAGEMENT PLAN PHASE 1- PRELIMINARY INVESTIGATION

2004

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REPORT BOOK 2004/9

Government of South Australia

MINERALS & ENERGY

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Preferred way to cite this publication
McLeary, M., 2004. Radium Hill Uranium Mine and Low Level Radioactive Waste Repository Management Plan Phase 1 - Preliminary Investigation 2004. *South Australia. Department of Primary Industries and Resources. Report Book,* 2004/9.

INFORMATION STATEMENT

This document has been prepared as phase 1 of an overall management plan being developed for the Radium Hill site. It has been compiled by the PIRSA Minerals Resources Group both as an internal document to aid in the management of the former Radium Hill Uranium Mine and Low-Level Radioactive Waste Repository, and to satisfy part of the conditions set out in Certificate of Registration No. 17153PP issued under the *Radiation Protection and Control Act 1982* for this same site.

The author has sourced available written information applicable to the site within the allotted timeframe to address relevant points, but the report is not intended to be an exhaustive compendium of the site or its history. The information supplied in this document is believed to be both reliable and accurate, however reliance is based on original documentation, and data being both correct and complete.

The reliability of information and data provided within this report must be considered in the following context:

- not all information and data required or requested have been located or forthcoming prior to the allotted time period for completion of the report
- former records, particularly in regards to inventories, have in a number of instances been found to be incomplete and inconsistent
- due to the extended time period since decommissioning of the site, some records have been permanently lost or destroyed
- in some instances, reports commissioned in more recent years have been utilised where original documentation has not been located.

The report findings within this document are therefore made on consideration and analysis of the information currently available.

A reference and bibliography are provided for readers interested in seeking further information where available on the various aspects and information contained within the report.

Note: A number of government working files referenced throughout this document are referred to by their original file number e.g.: SR 5/6/129, MO 7033/02, DM 160/54.

EXECUTIVE SUMMARY

This report is phase 1 of a management plan for the 'Radium Hill Mine Site and Low-Level Radioactive Waste Repository', and is essentially a preliminary investigation to establish a greater understanding of the characterisation of the site. Phase II will follow on from the phase 1 study and will be directed to a more detailed site characterisation incorporating additional studies and investigations. This will enable effective and informed decision-making on the future management of the site, and of the various remediation methods and options available. Phase 3 will see the development of an appropriate long-term management plan for the site.

This is a companion report to a similar report prepared for the former Port Pirie uranium treatment plant, and summarises a substantial amount of available information related to the Radium Hill Mine and low-level radioactive waste repository.

The Radium Hill area was first mined in the early 20th century for radium, however these early attempts were largely unsuccessful, and it was not until 1954 that a full-scale mining operation was initiated to produce uranium. The full-scale operation was commissioned and operated by the South Australian Government to satisfy a contract signed by the Commonwealth and state government with the UK–USA Combined Development Agency for delivery of uranium over a seven-year period.

After completion of the contract to supply uranium ore, the mine was decommissioned in 1961–62 and rehabilitated to the standard of the day. At the time, this included removing much of the infrastructure and sealing the underground workings, but it did not include the covering or armouring of the main tailings impoundment or waste-rock dumps. Over subsequent years (till 1981), material from the impoundment was dispersed over an area, largely to the south and southeast, through both erosion and wind deflation. In 1981, the decision was made to cover these impoundments with local soil material, and in the same year establish a low-level radioactive waste repository within the impoundment.

The mine itself is located in an isolated semi-arid region of South Australia and other than visits by Primary Industries and Resources South Australia (PIRSA) staff, property personnel and members of the Radium Hill Historical Association, the site is rarely frequented.

This report completes phase 1 of the overall management plan by providing a preliminary characterisation and conceptual model of the site, and includes:

1) consolidation of a considerable amount of site-related information and, where necessary and applicable, verifying and crosschecking this same information

2) supply of background data and assessment of the potential radiological exposure to humans and the environment

3) presentation of a preliminary 'risk assessment' based on selected scenarios relative to the radiological environment of the site

4) determination of data deficiencies and gaps and, where necessary, recommending further information and data required in order to progress to phase 2 of the management plan

5) provision of initial recommendations on current management strategies and initiatives where appropriate.

Key points resulting from this preliminary investigation include:

GENERAL

- A substantial collection of material related to the Radium Hill and Port Pirie operations is held and has been sourced in the preparation of this document. However, a number of former records, particularly inventories, have been found to be incomplete and inconsistent. In addition, due to the extended time period since decommissioning of the site, some records have been permanently lost or destroyed.

- There are no national or South Australian cleanup guidelines or threshold levels set for the remediation of former uranium mines or mills.

- The Radium Hill site is likely to require appropriate long-term management due to the long half-lives of many radioactive materials.

- A comprehensive communication and stakeholder consultation plan is required to effect and support the ongoing management process.

- Since 1998, no further low-level radioactive waste has been added to the low-level radioactive waste repository and, together with further recommendations from the EPA that the site would not meet current engineering standards, it is considered unlikely that the repository will see the burial of more material.

SITE-RELATED INFORMATION

- Within arid areas such as the Radium Hill environment, dust particles, gamma radiation and radon gas are the main contributors to the potential radiation dose.

- Whilst no definitive radiological studies have been undertaken in recent years, random sampling from the area indicates elevated gamma levels on areas of waste rock and mill tailings together with those areas where waste rock was used during development and operation of the former mine.

RISK MANAGEMENT

- People facing the greatest exposure (although considered to be minute) to elevated radiation levels based on current activities are those who spend extended periods of time at the site, namely overnight campers, etc.

- The potential subsidence of the mine workings and areas known to have been stoped towards the surface during mine operations remain an area of concern.

FUTURE CONSIDERATIONS

- Management of areas where radioactive contamination exists and remediation is considered does not imply the elimination of all radioactivity or all traces of radioactive material. The optimisation process may lead to extensive remediation but not necessarily to the restoration of pre-existing conditions.

- The Radium Hill site has limited potential future land uses due to a number of fundamental characteristics including:

    - natural elevated background radiation levels
    - remoteness from existing and likely future population centres
    - aridity
    - low relief
    - saline groundwater.

- Should remediation of the site be considered, the *Environmental Protection and Biodiversity Conservation* (EPBC) *Act 1999* may be triggered. It is recommended that a referral to the Commonwealth under the EPBC Act be prepared.

RADIUM HILL FACTS AT A GLANCE

Site description	Name	Radium Hill Mine. Originally operated and managed by the South Australian Government. Management of the site and repository remains with the state government.
	History	First discovered in 1906; major mining period from 1954–61. Ore concentrated on site before being railed to Port Pirie.
	Activity type	Underground mining, and surface concentrate mill.
	Current status	Mine decommissioned in 1961. From 1981, the tailings impoundment was used as a low-level radioactive waste repository. The last deposit was made in 1998, and the site is now inactive. Major restoration attempts undertaken in 1962 and again in 1981 with the covering of the tailings impoundment with soil.
Contamination	Radiological	No definitive studies undertaken. Random sampling however indicates elevated gamma levels on areas of waste rock and mill tailings together with those areas where waste rock has been used during development stages, e.g. foundations etc. Tailings material had dispersed over a wide area prior to covering in 1981.
	Chemical	Not determined.
Environmental monitoring	Ongoing	Visited by PIRSA staff, generally to inspect workings, signage and condition of the repository cover.
	Long term	To be determined.
Rock dumps	Description	Most of the waste rock and heavy-media rejects have been removed from site for use as railway ballast and road base material.
Tailings	Description	Tailings placement during 1954–61; some minor material produced prior to this relating to pilot plant testing. Top of tailings area used as a low-level radioactive waste repository since 1981.
	Size	Estimated at 225 000 tonnes covering an area of approximately 4 hectares.
Restoration costs	To date	Estimated at approximately $300 000, not including repository deposits or initial site cleanup following decommissioning.
	Future	To be determined.

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CHAPTER 1 — INTRODUCTION

1.1 BACKGROUND

The Radium Hill Mine is located in the remote northeast of South Australia, and was operated by the State Government from 1954 to 1961 for the recovery of uranium ore. Upon closure, the site was abandoned, access to mine workings were blocked and infrastructure was removed to the environmental standard of the day.

Two decades later, in 1981 following a reassessment of the site, further rehabilitation was undertaken and included additional backfilling of old mine openings and covering of the tailings impoundment. At the same time, the site was also established as a repository for low-level radioactive waste materials, primarily to facilitate the clean up of contaminated soil held in Thebarton in the Adelaide metropolitan area.

PIRSA Division of Minerals and Energy has retained management responsibility of the site for the government, and maintains a continuing watch on the site with radiological advice and assistance from the Radiation Protection Division of the EPA, formerly of the Department of Human Services.

1.2 PURPOSE OF THE REPORT

This report is phase 1 of an overall management plan being developed for the site, and has been prepared by PIRSA Mineral Resources Group as an internal document to aid in management of the former Radium Hill Uranium Mine and Low-Level Radioactive Waste Repository, in addition to satisfying part of the conditions set out in Certificate of Registration No. 17153PP issued under the *Radiation Protection and Control Act 1982* for this same site. This certificate of registration covers the area gazetted on 2 April 1981 as 'Reserved for Purposes of a Repository for Low Level Radioactive Materials'.

Note: The definition used in describing 'low-level waste' that will be used in this report is that given in the International Atomic Energy Agency (IAEA) Safety Series No. 53 (1981) and other IAEA publications, namely:

Those wastes, which because of their low radionuclide content, do not require shielding during normal handling and transport.

The purpose of this phase of the management plan is to provide a detailed report of existing site information based on a preliminary investigation and desktop study. It is also intended to identify areas where additional information is required for the development of a comprehensive site characterisation program.

The desktop study and report preparation has been undertaken concurrently to a similar report being prepared for the former Port Pirie Uranium Treatment Plant (PPUTP) that processed the concentrated ore exported from the Radium Hill Mine.

1.2.1 OBJECTIVES

The key objective of this report is to:

- provide a preliminary characterisation and conceptual model of the site in compliance with registration conditions.

Secondary objectives include:

- consolidate, verify and crosscheck information and knowledge of the site
- assess the potential radiological exposure to humans and the environment
- provide a preliminary risk assessment based on selected scenarios
- determine data deficiencies and gaps, and recommend further data that may be required for phase 2 investigations
- provide initial recommendations, where appropriate, on current management strategies and initiatives.

1.2.2 SCOPE

The main focus of this report is to provide a preliminary characterisation of the site and its radiological environment, and is largely targeted to the potential impacts on human health. Information relating to radiation and its effects on everyday life are presented in Appendix 2. The report is not intended to provide technical recommendations or sophisticated scientific procedures, but a broad overview of the site based on currently available information within the structure as set out below. It is also intended that the report will form a valuable tool in the preliminary stages of the overall decision-making process relevant to the site.

1.2.3 TARGET AUDIENCE

The initial intention was that this report would be written solely for addressing the conditions set out as part of the certificate of registration for the site. However, upon inspection of the vast quantity of material relating to the site, the scope was broadened to include further information and thereby increased the potential audience. As a result, this report on the Radium Hill Mine and Low-Level Radioactive Waste Repository site is intended principally for the following audiences:

- decision makers — as an aid in choosing appropriate strategies for the site
- departmental personnel — provides a concise background history and description of the site
- regulators — when evaluating management of the site
- consultants and contractors — when undertaking possible further site investigations

The document is also accessible to other stakeholders with an interest in the site.

1.2.4 STUDY PERIOD AND SOURCE MATERIAL

The desktop study component of this report, as previously discussed, was undertaken concurrently with the Port Pirie Uranium Treatment Plant study, and commenced in the second week of November 2003. A site familiarisation visit to the Radium Hill Mine site and low-level radioactive waste repository was undertaken by the author in January 2004.

A substantial collection of material is available on the Radium Hill and Port Pirie operations, with in excess of 3000 files, plans etc. being held in archival storage. The majority of these relate to the planning and operation of the mine and therefore date between 1950 and 1962. Due to the age of much of the data, and departmental changes resulting from government restructures, some information has been misplaced and/or destroyed over subsequent years.

Various documents, reports, plans and photos have been sourced from a number of locations. These have in turn been reviewed and collated and, where practical, used to verify and crosscheck a number of reports and briefs issued over the years, particularly those following decommissioning of the Radium Hill Mine in 1961.

1.3 REPORT STRUCTURE

This report is phase 1 of a management plan for the site and is essentially a preliminary investigation to enable the establishment of a primary characterisation of the site. The various phases are described as follows:

Phase 1: Phase 1 is a detailed report of existing site information based on a preliminary investigation consisting of a formal desktop study and site reconnaissance. From this, an initial conceptual model of the site is formed and hazards identified.

Phase 2: Phase 2 will follow on from the phase 1 study and will be directed to a more detailed site characterisation incorporating additional studies and investigations. This will enable effective and informed decision making on the future management of the site, and of the various remediation methods and options available.

Phase 3: Phase 3 will effectively be an 'Environmental and Safety Management Plan' for the site, and will provide a full characterisation of the site, including any planned remediation and ongoing maintenance and monitoring activities.

1.3.1 DOCUMENT LAYOUT

The chapters in this phase 1 report are:

Chapter 1. INTRODUCTION. Contains a brief background of the site, together with the objectives and structure of the report. It also contains the major legislative frameworks in place.

Chapter 2. SITE DESCRIPTION. Description of the regional and local environmental and socio-economic setting of the site based on available information.

Chapter 3. THE MINE SITE. A brief history and description of the operation of the various mining phases based on original plans, maps and early reports. The current status (2004) of these various areas related to the site is also provided.

Chapter 4. SITE CHARACTERISATION. Provides details from site characterisation studies, with the predominant focus being on the radiological attributes of the site. These have usually been undertaken as specialised studies following the closure of the site.

Chapter 5. MANAGEMENT and REMEDIATION. Examines past rehabilitation efforts together with more recent management initiatives and actions.

Chapter 6. RISK MANAGEMENT. Describes the various exposure pathways, and provides a conceptual site model of the radiological environment. The chapter also provides a **preliminary** risk analysis and assessment of the site based on available data and information. It is not intended to provide a final assessment of the present risks associated with the site, but is aimed more towards identifying further areas of investigation.

Chapter 7. RECOMMENDATIONS. Contains recommendations previously detailed in earlier reports and audits, together with further recommendations directed to current site conditions and the development of a comprehensive site characterisation plan.

BIBLIOGRAPHY. Is a list of documents, reports, etc. not only referenced to support the material located within this document but also read as general references in order to formulate the report.

APPENDICES. Includes further related information and provides details of units, prefixes, acronyms, and chemical symbols used throughout the report.

1.4 SITE CHARACTERISATION

Characterisation of the site is necessary to provide critical information and data in order to make informed decisions on the assessment and evaluation of the site.

The general approach to characterisation in support of remediation (if required) outlined by the International Atomic Energy Agency (1998 p.13) is to:

- define the objectives and strategies for the characterisation
- plan specific characterisation investigative tasks including important associated activities such as quality assurance, data management, and health and safety
- conduct the characterisation
- analyse and interpret the data
- report the results.

The characterisation of former mines and processing sites is often a difficult process due to a number of factors including:

- degradation of the sites
- undocumented mining and treatment methods
- successive episodes of operations often obscuring original operations and impacting over previous boundaries
- potential heritage and/or scientific-related issues
- previous attempts to remediate the sites often resulting from reactive decisions, and in many instances without full consideration to long-term effects and ongoing management.

1.4.1 SITE CHARACTERISATION PROCESS

Site characterisation is usually undertaken in a number of phases starting with preliminary investigations of available data and progressing to more advanced measurements to support the assessment of the site and/or problem.

This report is essentially the first of a number of steps to be able to fully characterise the site and consists of a formal desktop study and site reconnaissance.

1.4.2 CHARACTERISING RADIOACTIVE CONTAMINATION

The main focus of this report is on the radiological environment of the site and includes a number of methodologies and techniques. The International Atomic Energy Agency (1998 p.23) lists a number of possible radioactive contamination scenarios, including:

- a superficial distribution of deposited activity
- activity which has been deposited on the ground surface then migrated into the ground
- activity which has been buried or covered (e.g. by ploughing or building operations)
- activity which is to a greater or lesser extent distributed through a substantial depth of soil (e.g. waste tips)
- activity which is deeply buried (e.g. due to leakage from underground storage tanks or pipelines that have carried active material)
- activity distributed as 'hot' particles that are individually hazardous
- activity that is uniform over large areas or volumes; and localised hot-spots.

1.4.3 CHARACTERISING NON-RADIOACTIVE CONTAMINATION

Although this report focuses heavily on radioactive contaminants, in many cases non-radioactive contaminants often associated with the mining, milling and processing of uranium ores may arise and potentially could be of more concern than the radioactive components. It is likely that processes used in the past would have remaining residues and/or resulted in heavy metal concentration and disposal. When considering remedial design actions, the potential presence of these materials must be considered in addition to any health and safety issues that may result.

1.4.4 DEVELOPMENT AND IMPLEMENTATION OF A REMEDIATION PROGRAM

Upon completion of site characterisation studies, the preparation and approval of a remediation plan must be considered before undertaking any form of remediation. This includes:

'An appropriate assessment of both the radiological and non-radiological impacts of the situation and the benefits and detriments associated with possible remedial measures, including the associated restrictions and institutional arrangements following remediation[1], shall be performed and an optimum strategy shall be established.

Note: 1 'Remediation' does not imply the elimination of all radioactivity or all traces of radioactive material. The optimisation process may lead to an extensive remediation but not necessarily to the restoration of pre-existing conditions.' (IAEA 2003, p.3 and 10)

1.5 RADIATION PROTECTION STANDARDS

There are no National or South Australian cleanup guidelines or threshold levels set for the remediation of former uranium mines or mills.

1.5.1 INTERNATIONAL BODIES

The primary international bodies regarding health effects and control of radiation include:

- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)
- International Commission on Radiological Protection (ICRP)
- International Atomic Energy Agency (IAEA).

1.5.2 INTERNATIONAL CONVENTIONS

In November 1998, Australia signed the international Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management and, in order to ratify the agreement, sought an undertaking from the states and territories to have legislation and procedures in place to enable compliance with the convention. The convention requires, inter alia, that appropriate steps be taken to review the safety of any radioactive waste facility existing at the time the convention enters into force and ensure that, if necessary, all reasonably practicable improvements are made to upgrade the safety of such a facility. Australia ratified this joint convention on 5 August 2003 (Treaty database — DFAT, 2003).

To ensure that South Australia could comply with the requirements of the convention, the Radium Hill and Port Pirie sites were registered on 28 February 2003 as premises under Section 29 of the *Radiation Protection and Control Act 1982* (see section 1.5.5). Conditions attached to the registration were designed to permit the development of an appropriate long-term management plan for the site.

1.5.3 NATIONAL RADIATION STANDARDS

The National Health and Medical Research Council and National Occupational Health and Safety Commission (NHMRC, NOHSC) adopted recommendations by ICRP into national standards in 1994 in the publication *Recommendations for limiting exposure to ionising radiation and national standard for limiting occupational exposure to ionising radiation*.

A number of codes have been developed by the Commonwealth and the states, and include:

- Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores 1987
- Code of Practice on the Management of Radioactive Wastes from the Mining and Milling of Radioactive Ores 1982
- Code of Practice for the Safe Transport of Radioactive Substances 1990.

1.5.4 EPBC ACT

Under the *Environmental Protection and Biodiversity Conservation Act* (EPBC), there are six matters of national environmental significance, including 'nuclear actions'.

According to the criteria for 'nuclear actions' in the Commonwealth 'EPBC administrative guidelines on significance July 2000' (Environment Australia 2000), any action that includes establishing or significantly modifying a large-scale facility for radioactive waste or decommissioning or rehabilitating any facility or area associated with radioactivity may trigger the Act.

1.5.5 SOUTH AUSTRALIAN RADIATION PROTECTION REQUIREMENTS

In South Australia, regulation of radiation protection requirements is through the *Radiation Protection and Control* (RPC) *Act 1982*. Regulations under this Act include the *Radiation Protection and Control (Ionising Radiation) Regulations 2000* and the *Radiation Protection and Control (Transport of Radioactive Substances) Regulations 2003*.

Provisions of the RPC Act pertaining to radioactive material include the following:

- sealed sources, as well as premises in which unsealed radioactive material is used, handled or stored, must be registered
- uranium mining and milling operations must be licensed
- people using or handling radioactive material must be licensed
- there shall be a public register of licences and registrations issued under the Act (EPA, 2003).

As such, the Radium Hill site is a registered premise and a certificate of registration (Fig. 1) has been issued for the site under the RPC Act. It is described as a Type C waste disposal site with location details of the 'area of low-level radioactive waste repository — gazetted 02/04/1982'. Registration is granted by the South Australian Environmental Protection Authority and has been issued the registration number 17153PP, expiring on 30/11/2006. Conditions were set as part of the registration for the site (Box 1). Note: Corresponding chapters within this report are highlighted.

1.6 CHAPTER SUMMARY

This report will complete phase 1 of an overall management plan for the Radium Hill site. Phase 2 will follow on from this report and will be directed to a more detailed site characterisation incorporating additional studies and investigations where required in order to enable effective decision-making on the future management of the sites. A similar report for the Port Pirie Treatment site (where the uranium ore was treated) has also been completed; and address's similar conditions to those set out in the Radium Hill report as per the 'certificate of registration' under the RPC Act.

A substantial collection of material relating to the Radium Hill and Port Pirie operations is held and has been sourced in the preparation of the two reports. However, a number of former records, particularly inventories, have been found to be incomplete and inconsistent. In addition, due to the extended time period since decommissioning of the site, some records have been permanently lost or destroyed.

The key objective of the reports is to 'Provide a preliminary characterisation and conceptual model of the site in compliance with registration conditions', with the focus being on the radiological environment and the potential impacts on human health. However, it does not negate the presence or importance of any existing non-radiological contaminants, and these must be taken into account when considering remediation strategies.

Whilst regulation of the radiation protection requirements is through the South Australian RPC Act, should remediation of the site be considered then the Commonwealth EPBC Act may be triggered.

RADIATION PROTECTION AND CONTROL ACT, 1982

CERTIFICATE OF REGISTRATION: Section 29

Owner Number	19615
Docket Number	19615
Registration Number	17153PP

MINISTER FOR PRIMARY INDUSTRIES & RES. SA
PIRSA
GPO BOX 1671
ADELAIDE 5001

The person or organisation named above has been granted registration of the premises specified below on which unsealed radioactive sources are used or handled, pursuant to Section 29 of the Radiation Protection and Control Act, 1982.

Description of premises:

TYPE OF PREMISES : TYPE C
USE OF PREMISES : WASTE DISPOSAL SITE
LOCATION : AREA OF LOW LEVEL RAD WASTE
: REPOSITORY - GAZETTE 2/4/82

This certificate is valid from: 12/02/2003 and expires on: 30/11/2006

Pursuant to Section 36 of the Act, this registration is granted subject to the conditions set out in Schedule 3535 to this certificate.

ENVIRONMENT PROTECTION AUTHORITY

~~DEPARTMENT OF HUMAN SERVICES~~

IMPORTANT NOTICE

The Ionizing Radiation Regulations, 2000, require you to inform the Minister by notice in writing, within 14 days:

If your address for correspondence or for the service of notices changes,
OR
If structural alterations are made to the premises.

(Use the back of this form for notification of change of address.)

Fig. 1 *Radium Hill certificate of registration.*

Condition 3535

Former Uranium Mine Site Radium Hill

Condition of Registration

The occupier shall:

1) Ensure radiation hazard signs are in place in accordance with AS 1319-1994 'Safety signs for the occupational environment', and maintained in good condition. (Chapter 5 and Appendix 4)

2) Maintain integrity of existing waste containment structures. (Chapter 5 and Appendix 4)

3) Within 12 months from the date of registration, conduct a preliminary investigation of the site and provide a detailed report of existing site information including:

- History of site with emphasis on those activities associated with actual or potential contamination by radioactive materials and the physical and chemical forms of those materials, (Chapter 3, Chapter 4, Chapter 6 and Appendix 5)

- Description of waste management and disposal practices (Chapter 3 and Chapter 5, Appendix 5 and Appendix 8)

- Detailed maps of the facilities and environs including topographic and geomorphic features (Chapter 2, Chapter 3 and Chapter 4, Plan 1, Plan 2 and Plan 3)

- Previous survey or site characterisation data (geological and hydrogeological, condition of existing containment structures) (Chapter 2, Chapter 4 and Chapter 5, Appendix 6)

- Results of any surveys to identify and characterise the physical, chemical and radiological nature of contaminants present on or off the site, the potential migration pathways and receptors for the contamination. (Chapter 4 and Chapter 6, Appendix 6)

- An assessment of existing site security and safety arrangements. (Chapter 5 and Chapter 6)

- Indicate areas where additional information is required for the development of a comprehensive site characterisation program. (Chapter 7)

It is anticipated that these conditions will be reviewed 12 months from the date of registration in conjunction with the release of this report.

Box 1 *Conditions of registration — Radium Hill.*

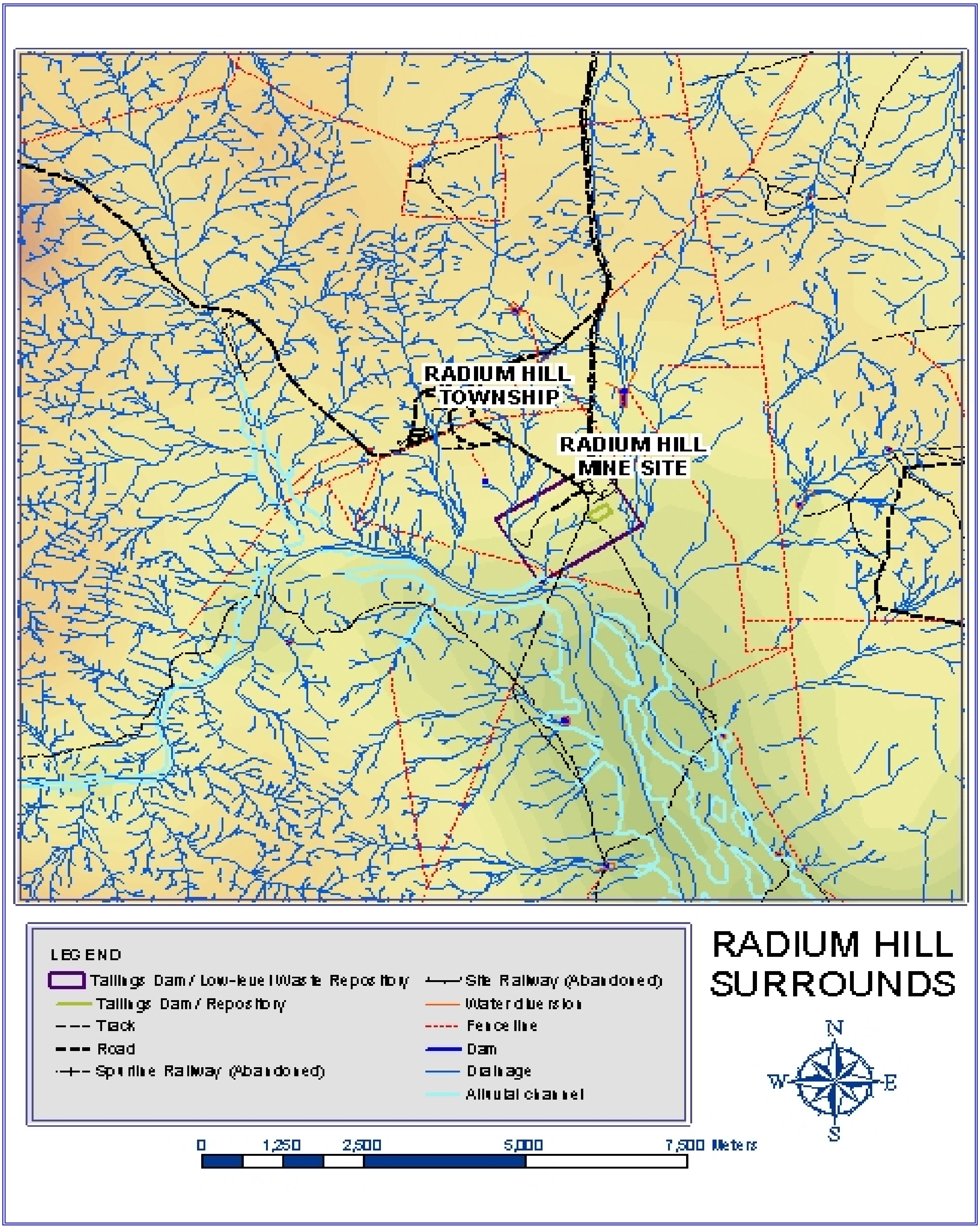


Fig. 2 *Topography and features of the Radium Hill environment (Source PIRSA)*

CHAPTER 2 — SITE DESCRIPTION

2.1 INTRODUCTION

In order to characterise a site, information on many aspects including the operational, geological, radiological, and socio-economic conditions is required. Ideally, baseline data collected and collated prior to and during the extractive and processing operations will aid considerably in determining long-term conditions, and is able to provide a meaningful background to measure remediation attempts. However, in a number of cases, particularly older sites, little information was recorded or is still in existence. Relevant regional information is therefore sourced to provide a basic understanding of the environment and, where necessary, more detailed site data collection is initiated to accurately describe and understand the characteristics of the site. This information is critical in understanding the site and can influence the design and implementation of any remedial actions.

2.2 PHYSICAL ENVIRONMENT

2.2.1 GEOLOGY AND SOILS

The following geological interpretation of the Radium Hill area (Fig. 3) has been provided by Alistair Crooks, Senior Geologist, PIRSA Mineral Resources Group.

2.2.1.1 GENERAL GEOLOGY

The geology of the Radium Hill area comprises a sequence of sediments and possible volcanics, called the Willyama Supergroup, deposited approximately 1700–1680 million years ago. During a period of extensive mountain building at around 1600–1580 million years ago, called the Olarian Orogeny, these sediments were deeply buried, highly deformed, partially melted and recrystallised. Subsequent erosion removed the mountains, bringing the deeply buried core back to the surface such that a new cycle of sedimentation occurred in this area 800–550 million years ago. These younger sediments, which can be seen in the hills extending from the mine managers house and the golf course to the west in the Radium Hill area, were subjected to a new round of deformation and mountain building 500 million years ago called the Delamerian Orogeny. On-going erosion since that time has reduced this mountain range to its current low relief, and re-exposed the Willyama Supergroup core of the earlier Olarian Orogeny mountain chain. Modern rivers draining the area, such as Olary Creek to the south of the mine site, show evidence of earlier cycles of stream sediments indicating that they occupy extremely long-lived palaeo-valleys.

2.2.1.2 GEOLOGY OF THE MINE SITE

Outcrop near the mine site is minimal and underground areas are no longer accessible. However, it is possible to see from the trend of the workings, through reconstructions from the geological reports, that the original mineralisation occurred as dense veins trending northeasterly, following the trend of the major fold axes attributed to the third phase of deformation during the Olarian Orogeny. High temperatures and pressures experienced deep in the mountain ranges during this deformation released uranium-rich fluids that were channelled into weaknesses in the anticlinal fold hinges. This fluid flow also resulted in intense alteration and the growth of new minerals, particularly biotite which occurs as ubiquitous black masses and spotting evident in the mine dumps. Initial fluids carried iron and titanium depositing ilmenite, subsequently replaced by davidite as uranium content increased.

The mineralisation is therefore considered to have been introduced during the Olarian Orogeny some 1580 million years ago. How much of the orebody had been eroded prior to deposition of the younger 800 to 550 million-year-old sediments cannot be determined. In addition, the volume of the orebody eroded during subsequent post-Delamerian Orogeny erosion cycles, and during erosion that has exposed the orebody now, is also unknown. However, the presence of cobble beds exposed in rubbish pits to the south and west of the mine site indicate active erosion channels in the area during the Tertiary Era (65–1.6 million years ago). This suggests that pre-existing, long-lived, natural dispersion pathways for Radium Hill orebody material are likely.

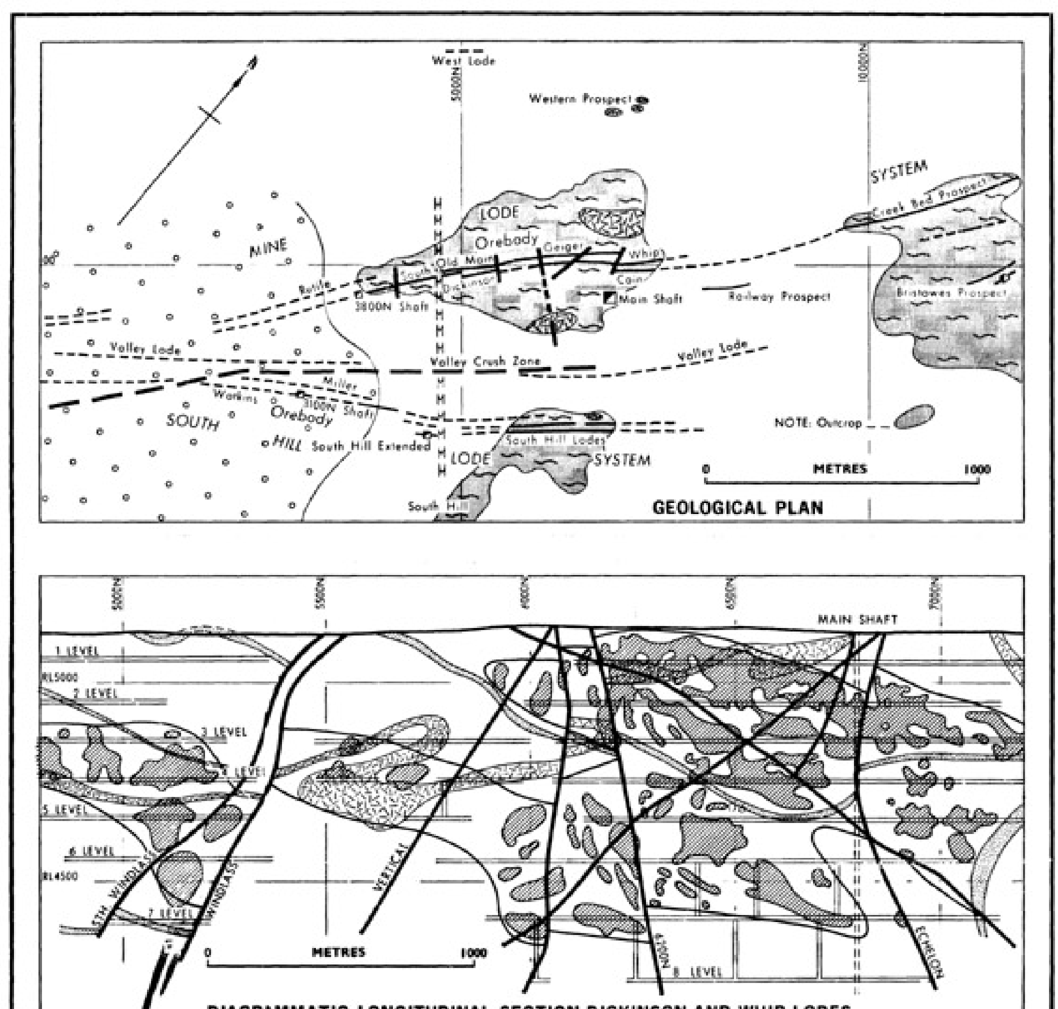


Fig. 3 *Geological plan and longitudinal section of the main lodes, Radium Hill, 1973. (Source: PIRSA 73-236)*

2.2.1.3 SOILS

Soils within the area are considered well-drained shallow loams. The area falls within the 'North East Pastoral' Soil Conservation District. Land management issues relevant to this district include:

- maintenance of native pasture
- control of pest plants and animals
- wind erosion
- water erosion.

Regional soil information sourced from the Australian National Resources Atlas (2004) mapping tool http://audit.ea.gov.au for the general Radium Hill area is presented in Table 1.

Table 1 *Regional soil characteristics. (Source ANRA 2004)*

	Topsoil	Subsoil
pH	7–8.5	5.6–8.5
Organic carbon (% organic carbon)	0.5–1.0	<0.3–1.0
Total nitrogen topsoil (% nitrogen)	<0.05–0.1	–
Total phosphorus topsoil (% phosphorus)	<0.02	–
Soil texture	sandy loam – loams	sand
Clay % subsoil (point model)	0–40	0–20
Saturated hydraulic conductivity	moderate	slow
Thickness soil (m)	Solum 0.6–0.9	0.3–0.6
% sand in soil	–	20–40

2.2.2 HYDROGEOLOGY

Information detailing hydrogeological conditions of the area is minimal and considered of limited value until further verification.

Localised (i.e. within 3 km) drilling of five holes for water in 1982 provided the following information:

Standing water level:	6–12 m below surface
Yield:	0–1.26 L/sec
Electrical Conductivity (EC)	13 400–52 000 µS at 25°C
Salinity	8 860–41 000 mg/L
pH	7.2–8.1

The groundwater in the area has also been described (Hill & Wilson, n.d.) as:

- 55 m below the surface

- containing 35 000 ppm total dissolved solids
- naturally contains 2–10 Bq/L of dissolved radium
- moving slowly towards Lake Torrens with salinity increasing towards 100 000 ppm TDS.

Note: It is believed that the groundwater level is closer to the surface than 55 m (as suggested above) within the mine area. Early mining reports from the mid-1920s indicate that a reasonable supply of water located within the then main shaft (13.7 m deep and located approximately 100 m west of the main 1950s shaft along the line of lode) was used as treatment water; also of note was that in very dry conditions this same water was used for drinking.

2.2.3 SURFACE HYDROLOGY

Whilst the terrain is relatively flat, surface drainage of the site is directed towards the south and southwest, flowing into the nearby Olary Creek within the lower Murray River Basin located within the Murray–Darling drainage division. A number of small dams have been built along some of the minor tributaries leading into Olary Creek; these include a set of three dams to the northwest of the mine site. It is believed that these were constructed during the mine establishment phase to provide water prior to completion of the main water pipeline from NSW.

2.2.4 TOPOGRAPHY

Radium Hill itself is a low ridge approximately 1 km in length and rising about 5 m above the surrounding plain. The area is generally flat to undulating, with a minor slope to the south; deep weathering has affected the region, and there are only isolated remnant outcrops (Fig. 2).

2.2.5 CLIMATE

The general climatic conditions are hot, very dry summers, cool to mild winters, and low rainfall. A weather station was set up to record daily rainfall and evaporation during 1951–61, covering the main mining period. Longer term recording stations within proximity of the Radium Hill area, at Broken Hill to the northeast and Yunta to the west, provide a greater range of information.

2.2.5.1 RAINFALL AND EVAPORATION

2.2.5.1.1 Local Information

Maximum daily and monthly rainfall data from the Radium Hill weather station is presented in Figure 4 for the period Jan. 1951 to Dec. 1961; a mean annual rainfall of 233 mm was recorded over this 11-year period. Annual evaporation for the same period was 2580 mm; Figure 5 shows monthly variances in mean monthly rainfall.

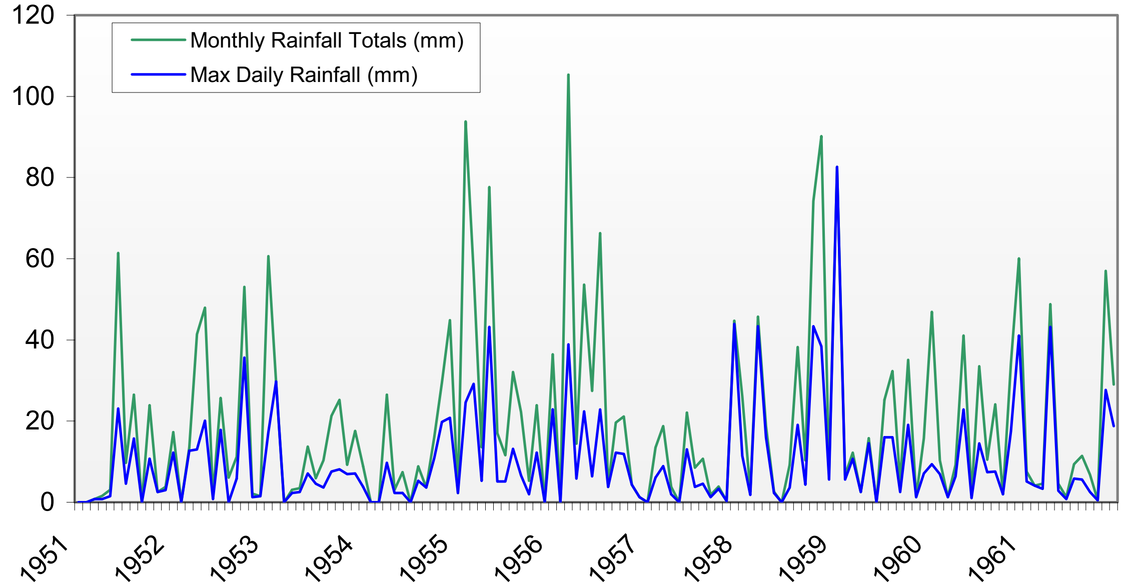


Fig. 4 *Radium Hill meteorological station — rainfall data 1951–61. (Data source: BOM 2004)*

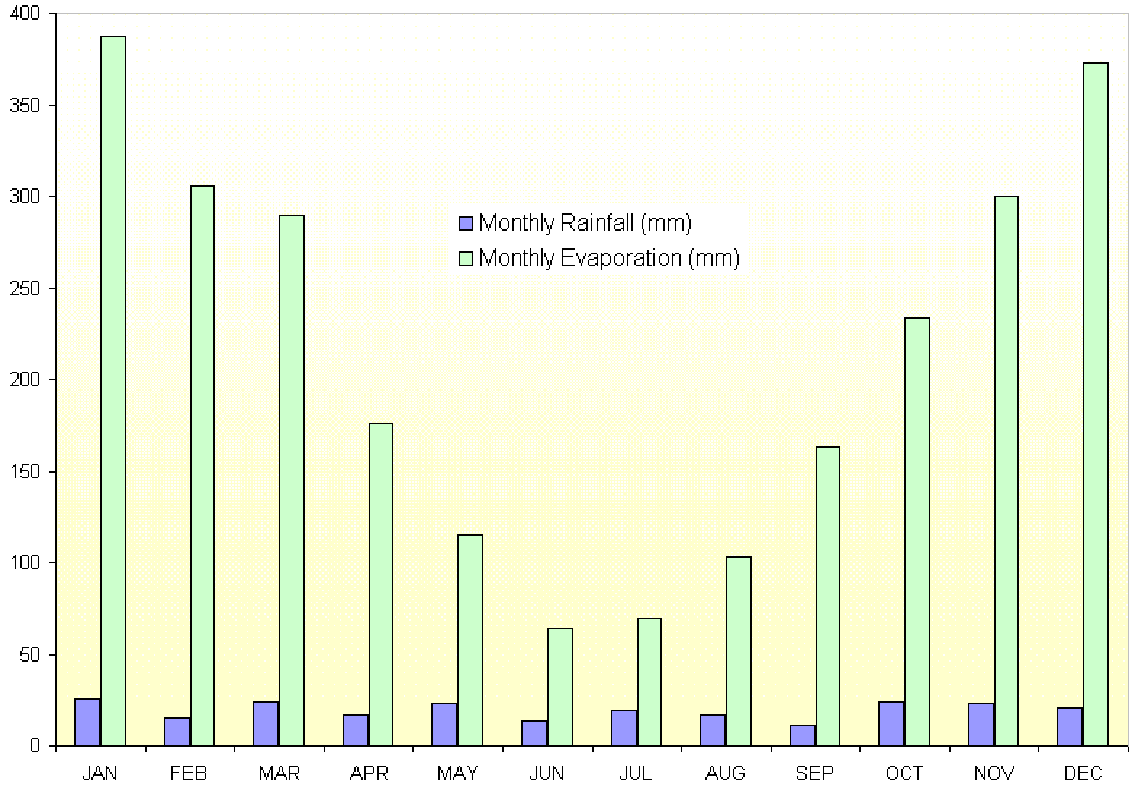


Fig. 5 *Radium Hill monthly rainfall and evaporation. (Source BOM 2004)*

2.2.5.1.2 Regional Information

Mean annual rainfall for all records at Broken Hill and Yunta is 255 mm and 236 mm, respectively. Rainfall can occur throughout the year, but extreme rainfall events are more likely in summer.

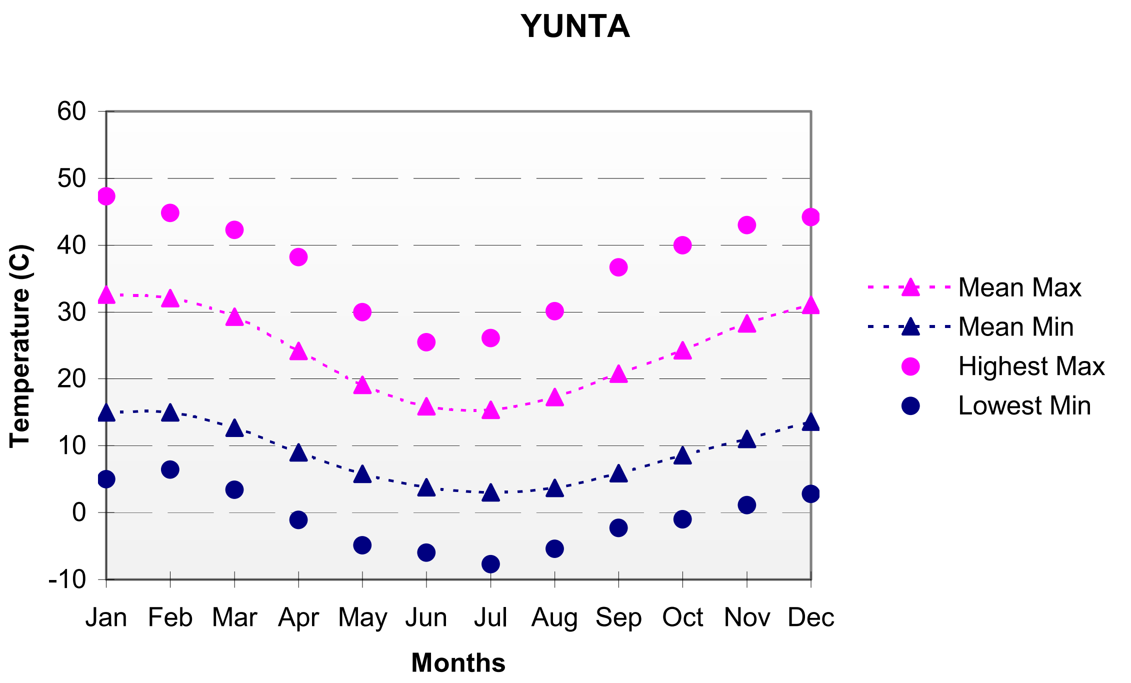
The two closest monitoring stations both have records dating back to the late 1890s and show the highest 24-hour rainfall event as 139.4 mm during March at Broken Hill and 112.3 mm during the same month at Yunta.

2.2.5.2 TEMPERATURE

Temperature information from Broken Hill and Yunta is presented in Figure 6. From November to March, mean maximum temperatures may exceed 30°C and daily temperatures may exceed 40°C. Average minimum temperatures for the same period are between 15 and 20°C. For the cooler months of May to September, mean minimum temperatures may fall below 10°C with daily temperatures falling below 1°C.

2.2.5.3 WIND

For the two monitoring stations at Broken Hill and Yunta, mean 9 am wind speeds of 9.3–15.4 km/hr and 9–15.9 km/hr, and 3 pm wind speeds of 13–16.2 km/hr, 11.4–16.7 km/hr, have been recorded, respectively.



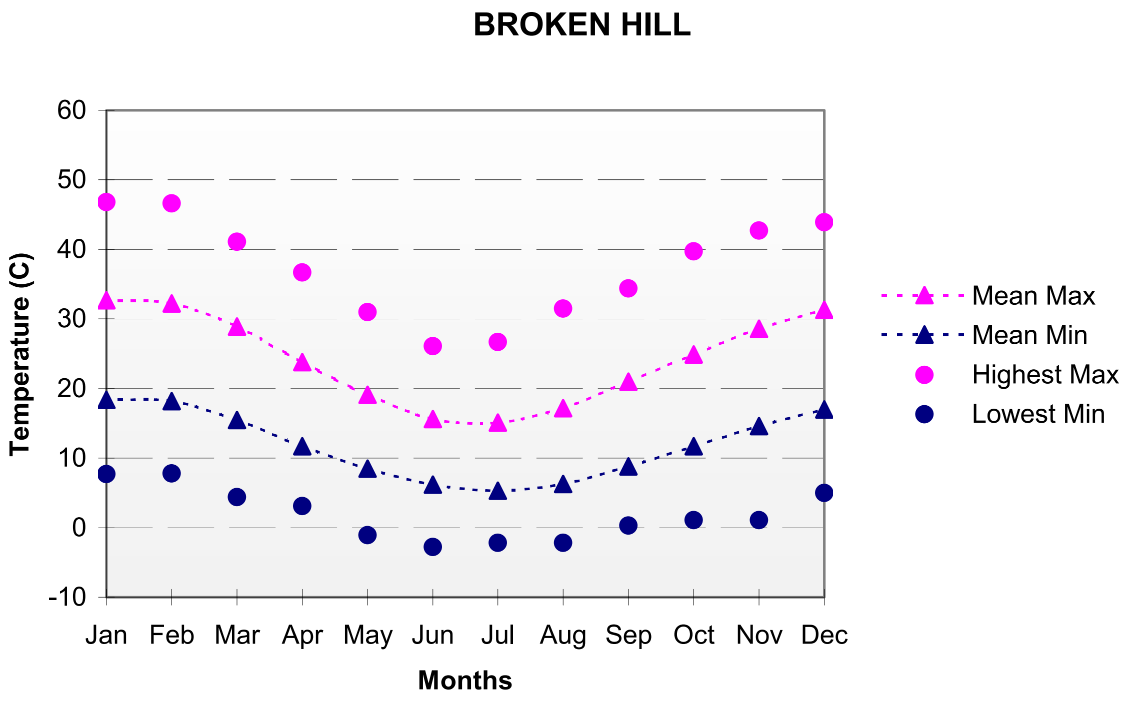


Fig. 6 *Yunta and Broken Hill temperature data. (Source: BOM 2004)*

2.3 BIOLOGICAL ENVIRONMENT

The Radium Hill site is a semi-arid area located largely within the Flinders Lofty Block Interim Biogeographical Regionalisation of Australia (IBRA), with the Broken Hill complex surrounding this to the south and east.

Whilst no systematic flora and fauna surveys have been undertaken within the Radium Hill area, some generalised comparisons can be drawn from field observations and more regional surveys undertaken as part of a biological survey of the North Olary Plains by the Biodiversity Branch, Department for Environment and Heritage, in 1996 (Playfair and Robinson, 1997).

2.3.1 FLORA

The Radium Hill area contains three floristic groups that are often associated together. These are described by Playfair and Robinson (1997) in *A biological survey of the North Olary Plains* and presented in Table 2.

Table 2 *Floristic group descriptions, Radium Hill area (after Playfair and Robinson, 1997).*

Floristic group	Very open shrubland	Low open shrubland	Very open low woodland
Distribution	Found along drainage lines, creeks and rivers.	Found on low, sandy rises and plains.	Confined to rocky hills in the Olary Spur.
Most frequent species	*Acacia victoriae* *Rhagodia spinescens* *Maireana pyramidata* *Scleroleana limbate* *Malvastrum americanum* *Enneapogon cylindricus* *Enneapogon avenaceus*	*Gunniopsis quadrifida* *Sclerolaena decurrens* *Rhagodia spinescens* *Maireana astrotricha* *Atriplex limbata*	*Acacia aneura* *Ptiltus obovatus* *Sida petrophila* *Solanum ellipticum* *Cheilanthes lasiophylla* *Eremophila freelingii* *Acacia tetragonophylla* *Enchylaena tomentosa*
Vegetation condition	Extensively invaded by *Asphodelus fistulosus* (Onionweed), *Medicago polymorpha* (Burr medic) and *Sisymbrium erysimoides* (Smooth mustard).	Likely that stock trampling has a considerable impact.	Where easy access is available, this community has been heavily impacted by grazing.

Within the mine site, the most prevalent tree species noted was introduced pepper trees (S*chinus molle*) growing around many of the foundations, etc.

2.3.2 FAUNA

The area is extensively used for grazing for the production of wool, and has continued throughout the broader area for over 150 years.

In terms of fauna that may exist within the area, some comparisons may be drawn from surveys throughout the general North Olary Plains, although the closest fauna monitoring site (to Radium Hill) was located some 50 km away.

2.3.2.1 BIRDS

The following list is derived from the 1996 survey conducted by Playfair and Robinson (1997). Only those species with a chenopod grassland habitat preference are included. It is expected but not guaranteed that many of these species may also be found within the Radium Hill area.

Species	**Common name**
Anthus novaeseelandiae	Richard's Pipit
Ashbyia lovensis	Gibberbird
Calamanthus campestris	Western Fieldwren
Cincloramphus cruralis	Brown Songlark
Cinclosoma cinnamomeum	Cinnamon Quail-thrush
Circus assimilis	Spotted Harrier
Elanus scriptus	Letter-winged Kite
Epthianura albifrons	Galah
Epithianura aurifrons	White-fronted Chat
Epithianura tricolor	Crimson Chat
Falco cenchroides	Australian Kestral
Malurus leucopterus	White-winged Wren
Neophema chrysostoma	Blue winged Parrot
Peltohyas australis	Inland Dotterel
Psophodes cristatus	Chirruping Wedgebill
Turnix velox	Little Button-quail

2.3.2.2 MAMMALS

The following list of mammal species known to occur in the North Olary Plains region has been compiled by Playfair and Robinson (1997) and from SA Museum records. As with the previous section on birds, it is expected but not guaranteed that many of these species may also be found in the Radium Hill area.

Species	**Common name**	**Conservation status (SA)**
* *Bos Taurus*	Cattle	–
* *Equus caballus*	Horse	–
* *Felis catus*	Cat	–
* *Capra hircus*	Goat	–
* *Mus domesticus*	House Mouse	–
* *Oryctolagus cuniculus*	European Rabbit	–
* *Ovis aries*	Sheep	–
* *Vulpes vulpes*	European Fox	–
Canis familiaris	Dog and Dingo	–
Leggadina forresti	Forest's Mouse	Rare
Macropus fuliginosus	Western Grey Kangaroo	–
Macropus giganteus	Eastern Grey Kangaroo	Vulnerable
Macropus rufus	Red Kangaroo	–
Nyctophilus geoffryi	Lesser Long-eared Bat	–
Planigale gilesi	Giles' Planigale	Uncommon
Planigale tenuirostris	Narrow-nosed Planigale	Uncommon
Pseudomys bolami	Bolams' Mouse	–

Sminthopsis crassicaudata	Fat-tailed Dunnart	–
Sminthopsis macroura	Striped-faced Dunnart	–
Tachyglossus aculeatus	Echidna	–

* Introduced species.
SA status is from Kemper and Queale (1990).

During a 2004 site visit, a number of non-native fauna species including goats and rabbits were observed, along with the farmed sheep.

2.3.2.3 REPTILES AND AMPHIBIANS

During the North Olary Plains Survey (Playfair and Robinson, 1997), a number of reptiles were recorded, with the more frequently observed species including:

Species	Common name	Habitat preference
Tliqua rugosa	Sleepy Lizard	G
Gehyra variegata	Tree Dtella	A
Pogona vitticeps	Central Bearded Dragon	G
Heteronotia binoi	Bynoe's Gecko	G, F
Morethia boulengeri	Common Snake-eye	G, NS, F
Ctenotus schomburgkii	Sandplain Ctenotus	G
Lerista labialis	Eastern Two-toed Slider	S
Morethia adelaidensis	Adelaide Snake-eye	C (H)
Crytoblepharus plagiocephalus	Desert Wall Skink	A
Menetia greyii	Dwarf Skink	G, F
Ctenophorus nuchalis	Central Netted Dragon	S
Ctenotus regius	Eastern desert Ctenotus	G (C)

Habitat preference:

A	Arboreal
C	Chenopod shrubs
F	Fallen trees
G	Generalist
H	Heavy soils
NS	Non-sandy
S	Sandy soils

2.4 SOCIO-ECONOMIC ENVIRONMENT

2.4.1 DEMOGRAPHICS

The Radium Hill area falls within the Unincorporated Pirie Statistical Local Area (SLA 435159459) located in the mid-eastern portion of the state, and incorporates the railway townships of Cockburn, Olary and Yunta. The area is characterised by a sparse population (340 inhabitants) in an area of approximately 38 000 km^2 (ABS, 2001), representing approximately one person for every 110 km^2. The closest residence to the Radium Hill site is 20 km away.

2.4.2 LAND TENURE

Whilst access to the Radium Hill Mine site is predominantly made via Tikalina Station to the north, the mine and surrounding land is located on Maldorky Station and includes portions of Pastoral Blocks 961 and 1192.

No mining leases are current within the general area, but much of the area surrounding the mine site is covered by two (2004) exploration licences, both taken out in the pursuit of base metals including zinc, lead, silver, copper and gold. These licences do not include the area exempted under the Mining Act covering the actual repository site and main mine workings.

There are no proclaimed National Parks and Wildlife Reserves within the district.

2.4.3 LAND USE

The main land use is sheep grazing for wool production. The mine site (predominantly the town area) is visited by the public on an infrequent basis, including members and associates of the Radium Hill Historical Association.

2.4.3.1 RADIUM HILL HISTORICAL ASSOCIATION

In 1990, following responses to a survey of former Radium Hill residents, the 'Radium Hill Community Association' was formed. Over the subsequent years (including a renaming to the 'Radium Hill Reunion Committee'), a number of reunions have been held at the former town site, the cemetery rehabilitated and a book titled *We were Radium Hill* has been published.

Recently, the name was changed to the Radium Hill Historical Association in addition to the development of a new website, where the history of the site is provided together with details of upcoming events, newsletters etc.

'The objectives of the Association are to establish and preserve the historical and cultural heritage of the former Radium Hill town, Pioneers Cemetery, and Heritage Museum. To act as a focus regarding news, information and welfare of former Radium Hill residents and their families.'

2.4.4 CULTURAL ENVIRONMENT

There is a very long Aboriginal history in the Olary district, with the Wiljakali tribe traditionally occupying the general Radium Hill area. These people lived in small family groups, with their movements controlled and directed by seasonal conditions (Playfair and Robinson, 1997). No formal archaeological studies have been conducted within the area. A search of the *Register of the National Estate* and the *South Australian Heritage Register* did not yield any listings within the immediate vicinity of the Radium Hill Mine.

2.5 CHAPTER SUMMARY

The Radium Hill site is located in a semi-arid area in the northeast of South Australia, 35 km from the NSW border. General climatic conditions consist of hot, very dry summers, cool to mild winters and low rainfall. The area is characterised by a sparse population represented by one person per 110 km^2. The actual mine site is not readily accessible and is visited on an infrequent basis by members of the public.

Although similarities can be drawn from regional studies, other than detailed geological interpretation and mapping studies, and limited climatic data of the site between 1951 and 1961, no systematic or detailed surveys have been conducted within the Radium Hill Mine area to record the physical, biological and socio-economic environment.

CHAPTER 3 — THE MINE SITE

3.1 INTRODUCTION

Following the initial mineral discovery in 1906, a number of mining operations attempted to extract radium, but it was not until the 1940s that the potential for uranium was fully realised and, as a result, requests were made by the British and American governments to set up a mining and processing operation to produce yellowcake.

This full-scale operation was commissioned and operated by the South Australian Government to satisfy a contract signed by the Commonwealth and state government with the UK–USA Combined Development Agency for delivery of uranium over a seven-year period.

The ore resulting from the Radium Hill mining project was concentrated on site by flotation then railed approximately 280 km southwest to Port Pirie on Spencer Gulf, where yellowcake was produced by an acid leach and ion exchange process.

3.2 HISTORY

3.2.1 PRE-1952

In 1906, A.J. Smith, who mistook a dark coloured ore for tin, inadvertently made the first discovery of a radioactive material at Radium Hill. Sir Douglas Mawson identified uranium within the sample and named it davidite after the late Sir Edgeworth David. Following this initial discovery, the area was worked intermittently for the recovery of radium (for medical purposes), although all operations were considered unsuccessful. A few hundred kilograms of uranium were also produced largely as a by-product, and it is believed that this was used as a bright yellow pigment in glass and ceramics. Many of these earlier workings were to be incorporated into later mining operations. The following timescale describes activities carried out between the discovery in 1906 and the start of formalised mining in 1952.

- 1906 — Discovery by A.J. Smith.
- 1906–08 — Claim at Radium Hill pegged in search of rare radioactive minerals, then abandoned.
- 1909–15 — Claim taken up again (by the Radium Hill Company), with numerous shafts being sunk, a magnetic concentrating plant erected in 1911, and a treatment works being built at Woolwich on the Parramatta River near Sydney. Concentration of uranium minerals was effected by dry-crushing to 3 mm then by magnetic separation following hand sorting. By the end of 1912, 120 tons of concentrate had been smelted, of which 95 tons were treated for approximately 350 milligrams of radium bromide (Gee, 1913). A further 239 milligrams were produced in the 1913–14 financial year from an estimated 130 tons of ore (Gee, 1914). Numerous other claims were taken up in areas surrounding the main site, with some exploratory mining and minor production attempted.
- 1923–31 — A new company (Radium and Rare Earths Treatment Company NL) formed, with minor production before abandonment (Fig. 7). Mineral concentration was carried out on site by gravity separation with

wet shaking tables after crushing the ore to 3 mm, before being sent to Dry Creek in Adelaide for processing.

- 1940–44 — Investigations undertaken by the Australian Mining and Smelting Company of Melbourne (SR 11/2/63), although no action taken. Attempts were also made during this period to secure markets for radioactive concentrates.

- 1944–52 — Initial investigations started in 1944, with the main exploratory focus being between 1947 and 1951. By 1949, exploration at Radium Hill had indicated enough ore to warrant investigation by shafts and drives, and in the same year a decision was made to erect a crushing and sampling plant at the site to assist underground exploration. The initial separation of material using a magnetic separator was principally chosen over other methods as it required minimal use of water. By the end of 1950, approximately 100 people were employed on the field, and the decision to undertake large-scale production was made in March 1952.

- 1952 — Mining operations commenced.

Fig. 7 *Radium Hill Mine, 1926. (Source: PIRSA N001346)*

3.2.2 1952–61

Substantial development work was undertaken prior to full-scale operations using conventional mining methods commencing in November 1954. The lodes were initially opened up by sinking of the main shaft, then development of a system of levels.

The extraction of uranium from the Radium Hill ore was undertaken in two distinct operations — the concentration on site at Radium Hill, then chemical extraction after shipping to Port Pirie. Approximately 854 000 t of ore grading approximately 1100 ppm U were extracted and milled to produce 120 000 t of concentrate for treatment at Port Pirie to produce approximately 850 t of U_3O_8.

3.2.2.1 MINE PRODUCTION

Mine production figures presented in Table 3 are derived from information in Rodgers (1960) as cited in Wilson (1996) for the period up to December 1960, and from December 1960 include overall totals from departmental records in SR5/6/129 vol. 3.

Table 3 *Radium Hill Mine production figures, 1955–61. (Source PIRSA)*

	Ore production		Est. uranium oxide (U_3O_8)
	Production t	Tonnes per day	Avg. grade kg/t
Jan 55 – June 56	152 575	325	
1956 – 1957	108 740	347	
1957 – 1958	112 307	359	
1958 – 1959	121 068	387	
1959 – Dec 1959	66 123	423	
Jan 1960 – Dec 1960	143 828	394	0.967
Jan 1961 – 15/11/1961	149 819	410	0.987
Total to 15/11/1961	**854 460**		**1.094**

3.2.3 POST–1961

Following closure of the site in 1961, much of the infrastructure and buildings were dismantled and/or removed, together with some remedial measures considered suitable for the day being undertaken. This largely involved the backfilling of a number of the mine openings, and possibly (although not verified) minor armouring of the main tailings impoundment at the same time. Following the decommissioning period, a number of exploration companies have been active in the area, generally in pursuit of minerals other than uranium. In addition, some minor testing of the tailings material has been carried out to determine quantities of rare earth elements (REE) and the potential extraction of these minerals.

3.2.3.1 ORE RESERVE ESTIMATES

Estimates were made of ore reserves immediately following the completion of the seven-year contract at the end of 1961 (Table 4).

Table 4 *Radium Hill ore reserve estimates, 1961. (Source: Cotton, 1979)*

Category	Tonnes	Grade (kg/t)	Kg U_3O_8	Location
Measured: Tonnage and grade computed from results of detailed underground sampling and based on previous mine experience.	45 039	1.089	55 019	Main and South Hill Lodes (i.e. worked lodes)
Indicated: Computed partly from results of sampling and partly from projection based on geological evidence.	68 428	0.953	71 766	Main and South Hill Lodes.
Inferred Category A: Computed largely on geologic evidence aided by scout diamond drilling.	246 197	0.816	215 708	Main and South Hill Lodes.
Inferred Category B: Educated guess based on very limited diamond drilling.	435 448	1.043	505 756	South Hill Lodes and four other separate lodes.

3.2.4 AREA EXEMPT FROM THE MINING ACT

On 28 August 1975, a rectangular area 1900 x 1300 m (totalling 247 ha) was gazetted as being exempt from operation under the provisions of the Mining Act, thus preventing any mining interests from taking possession of the area for mining purposes.

The area is described as those portions of Pastoral Blocks 961 and 1192 bounded as follows: commencing at a point due east of and 2100 m distant from the southwestern corner of Pastoral Block 1192, thence northeasterly at a true bearing 58° for 1900 m, southeasterly at a true bearing of 148° for 1300 m, southwesterly at a true bearing of 238° for 1900 m, thence northwesterly to the point of commencement. The exempt area contains:

- the main area of mineralisation that was disturbed by underground mining
- the surface area disturbed by mine facilities such as:
- engineering workshops, power generator, and mine hoisting facilities
- mine office, laboratory and associated buildings
- the metallurgical treatment plant
- the waste aggregate stockpile areas, and the fine sand tailings storage facility.

3.2.4.1 GAZETTED AREA UNDER THE CROWNS LAND ACT (1929–80)

The boundary of the same area exempted from the Mining Act as described above was gazetted on 2 April 1981 as 'Reserved for Purposes of a Repository for Low-Level Radioactive Materials' (Fig. 2 and Plan 2), and is referred to again in subsequent sections.

3.3 SITE LAYOUT

Very little remains of the pre-1952 operations other than some foundations where it is believed the treatment plant and possible support infrastructure once stood during the main operations from the 1920s. The 1952–61 Radium Hill Mine site operations largely comprised the mine and mill site, the township and associated support infrastructure, described in further detail in the following functional components relating to Plan 1.

3.3.1 MINE WORKINGS

For the main mining period (1952–61), the mining method was by hand-held machines in narrow-seam inclined open stopes. Lode widths were generally narrow, with a mean mining width of 1.2 m, and a maximum width indicated to be 6 m on rare occasions (South Australian Department of Mines, 1961). The shears mined for ore generally dipped 50–60º, and from mine plans it appears that stoping occurred on these to within 3.3 m of the surface. The ore was dropped on the rill to the chute fronts (Fig. 8) located on the level below, from where it was manually loaded into 1 t rail trucks for haulage to the main shaft and for hoisting to the surface. By the completion of operations, the mine had been opened up to a length of approximately 1200 m, with the main shaft reaching 417 m in depth.

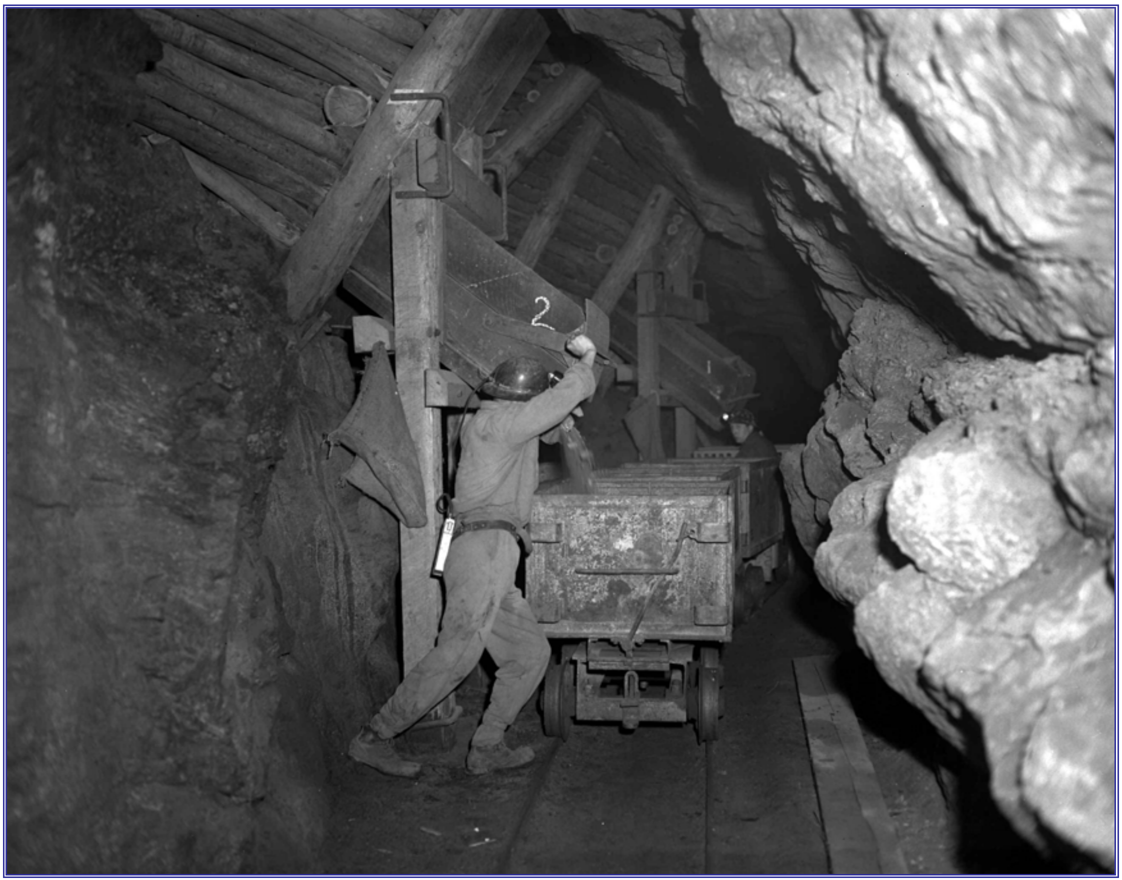


Fig. 8 *Loading ore trucks underground at Radium Hill in the 1950s. (Source: PIRSA N007463)*

During and nearing completion of mining, a number of reports were produced discussing various options for the filling of the workings, but no evidence can be found of any of these methods being adopted. It is known, however, that waste rock etc. was used to fill many of the openings following closure.

3.3.1.1 MINING METHOD

The following description of the mining method employed at Radium Hill is extracted from a report by Wilson (1996) investigating the exposure of occupational mine dust at the mine.

A new main shaft was sunk at 6800N (feet north on the mine survey grid). Full-scale mining began in 1954 and the mine was officially opened on 14 November of the same year.

The mining equipment and method used was conventional for that time in Australia. Horizontal levels with 24 inch (600 mm) gauge rails supported 1.5 ton battery locomotives, side tipping trucks (0.6 m^3), air-powered boggers — Eimco 12Bs and caterpillar tracked Eimco 630s (O. Puccini, pers. comm., 1996, MESA). Drilling was done using pneumatic air-leg supported hand-guided rock drills operated at 60–90 psi (~400–600 kpa) air pressure.

Mining levels (Fig. 9) were constructed at 100-foot (30 m) intervals to the 600-foot (180 m) level, 150 feet (45 m) thereafter, and followed the ore down to a depth of 1300 feet (400 m) and for a strike length of about 6000 feet (1800 m). There were some old workings on a 50-foot level. Rises and possibly winzes between the levels were used to test the ore zones, and overhand stopes and shrink stopes were developed in the ore zones defined by the development rises and sub-levels.

Whereas the surface drilling indicated reasonably continuous shoots (also referred to as seams, reefs and lenses) of mineable ore, mine development at depth subsequently showed the mineralisation to be en echelon in nature. This complicated the mining sequence as levels often did not connect on a rise (inclined mine development) in ore. The original estimated grade of 4.6 lb/ton (0.2%) was not achieved, probably because of the structural eccentricities causing a misinterpretation of the ore-shoot system.

3.3.1.2 PRESENT STATUS

Shafts, winzes and areas stoped to surface either have been backfilled or access limited by placement of concrete caps. Much of this was undertaken upon decommissioning the mine site in the 1960s, however further work has been carried out in subsequent years together with periodical inspections to assess the integrity and, where necessary, repair of these closures. See Appendix 7 and Chapter 4 for further details.

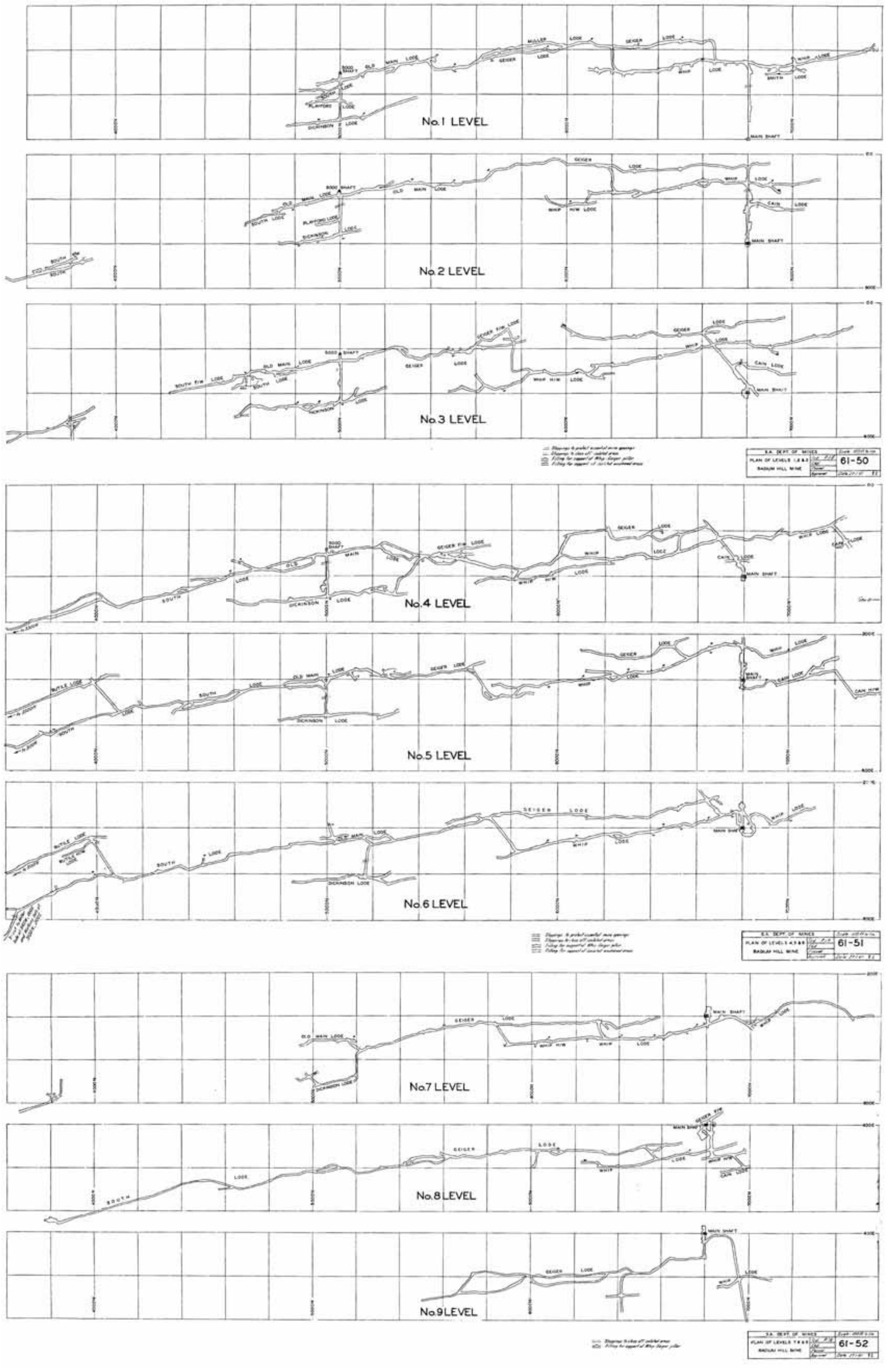


Fig. 9 *Plan of levels 1–9, Radium Hill Mine. (Source: PIRSA 61-50, 61-51, 61-52)*

3.3.2 MINE SURFACE INFRASTRUCTURE AREA

The mine surface infrastructure included the headframes, winding houses, compressor house, change rooms, crusher house etc (fig 10).

Fig. 10 *Radium Hill Mine headframe, winding house (right) and compressor house (left); the ore hoppers are located directly behind (not visible) the hoist; 1954. (Source: PIRSA T000002)*

3.3.2.1 PRESENT STATUS

Other than the ore hoppers and part of the crusher house adjacent to the main shaft, the only other remnants following removal and/or demolition are the concrete foundations and minor related refuse.

3.3.3 MILL AND TREATMENT AREA

This area includes the main mill and treatment area located immediately south of the main shaft (Fig. 11). The ore was concentrated at Radium Hill by heavy media separation and flotation to produce a concentrate containing about 0.7% U.

Fig. 11 *Southerly view from the top of the Radium Hill headframe, overlooking the mill and ore bins; waste rock and reject piles are in the background; circa 1957. (Source PIRSA T022446)*

3.3.3.1 TREATMENT PROCESS

Figure 13 diagrammatically presents the overall treatment process flow, which essentially comprised the mined ore being crushed by a two-stage process, firstly to 70 mm, then to 25 mm, prior to initial gravity separation. From this the ore was washed then the +10# material was fed to a heavy-media separation unit, whereupon the tailings are discarded and the heavy concentrate ground ready for flotation. The –10# fines were also ground and added to the material from the =10# feed into the flotation circuit. The ground product at this stage was 66% -200#. The final concentrate was then thickened, filtered and loaded into open rail trucks, sampled for moisture and uranium content, then despatched to Port Pirie.

3.3.3.2 PRESENT STATUS

On completion of mining operations, much of this area was demolished and/or removed. Two ore bins are still standing (Fig. 12) and at present appear to be in good structural condition. Other than concrete foundations and minor related refuse, little remains of this area.

Fig. 12 *Northerly view of the Radium Hill mill area and ore bins in 2004. (Source: PIRSA 049701)*

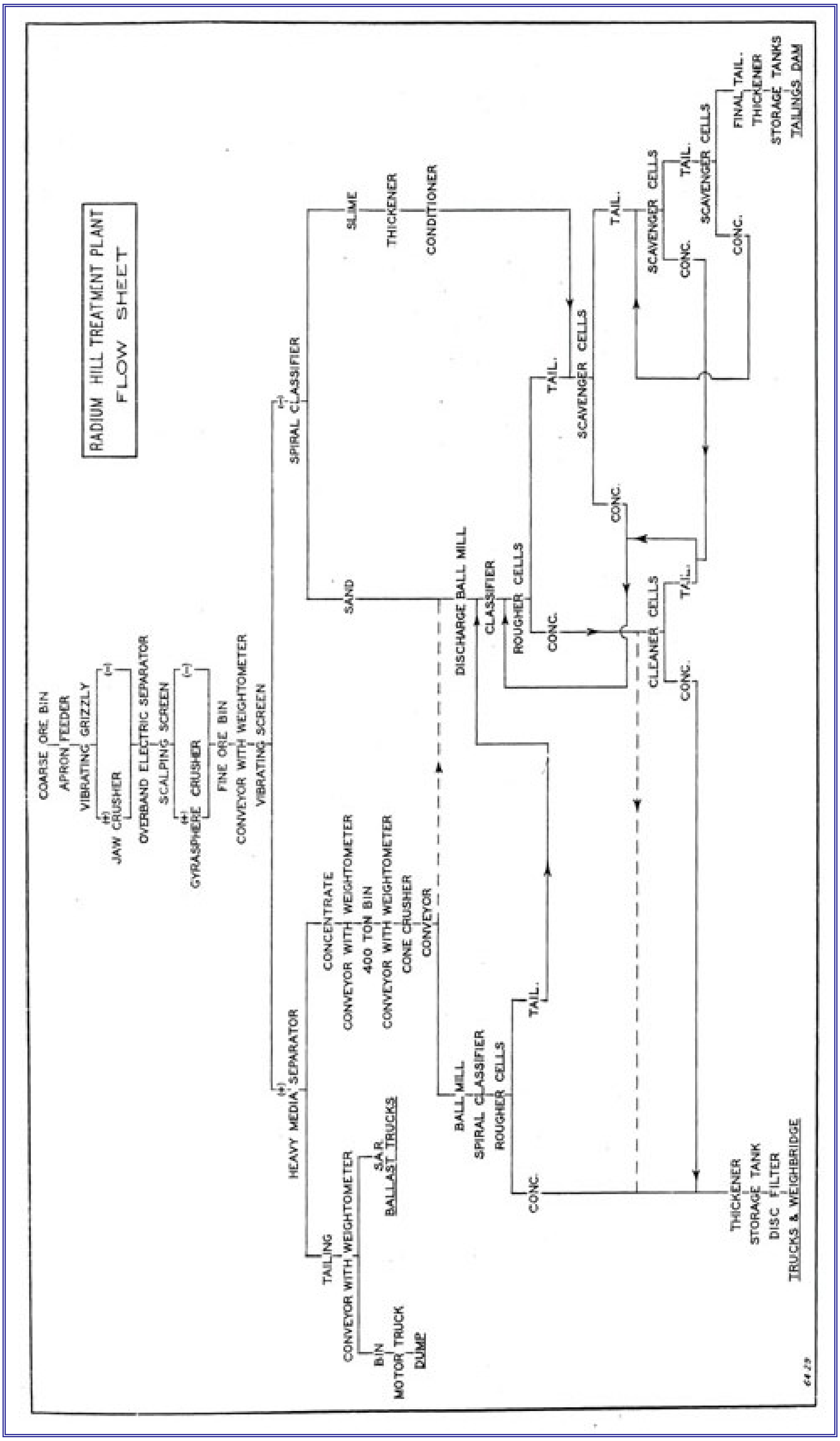


Fig. 13 *Radium Hill treatment plant flow sheet. (Source: PIRSA 64-29)*

3.3.4 SUPPORT BUILDINGS

The area of support buildings included the administration and technical buildings, the workshops, transformer station, main store, fuel depot and South Australian Railways buildings, all located immediately to the west and north of the main shaft area (Fig. 14).

Fig. 14 *Northwesterly view from the top of the Radium Hill headframe over the top of the compressor house towards the workshop area, 1957. (Source: PIRSA N007849)*

3.3.4.1 PRESENT STATUS

On completion of mining operations, all of these buildings were either demolished or removed and, other than concrete foundations and minor related refuse, little remains of any of these structures.

3.3.5 SUPPORT INFRASTRUCTURE

Support infrastructure included the roads, rail lines, airfield, water and power lines etc. used in the development, utilisation, decommissioning and subsequent access of the Radium Hill Mine site. Originally electrical power was by means of a high-voltage transmission line from Morgan, approximately 200 km to the southwest, and water was piped from Umberumberka Reservoir near Broken Hill. For the purposes of this report, infrastructure will only include those portions within the actual mine area.

3.3.5.1 PRESENT STATUS

Following completion of mining, power and water supplies were disconnected during 1961–62 and lines removed, including the powerlines in 1963. Much of the original road network is still evident although in disrepair; the railway is also readily recognisable although the tracks and sleepers have been removed.

3.3.6 TAILINGS IMPOUNDMENT

The tailings resulting from mining operations at the Radium Hill site were placed in a rectangular heap (Fig. 15) consisting of two sections each approximately 125x125 m and covering a total area of approximately 4 ha. This method of placement is commonly referred to as a ‘turkey nest’ impoundment where tailings are confined by constructing a self-containing structure (normally either circular or rectangular), which closes upon itself. These would normally be built with very little preparation to the ground surface.

Fig. 15 *Radium Hill Mine tailings impoundment, viewed southwesterly from the top of the headframe, in the 1950s. Note the spillage of material to the left. (Source: PIRSA T004525)*

Following decommissioning of the site, the tailings impoundment was not covered, which resulted in erosion of the walls and dispersion by wind and water of substantial amounts of the tailings material to the surrounding area. In 1981, the impoundments were covered with soil, using material from four adjacent borrow pits. The decision not to armour the tailings with rock material was due to financial restrictions at the time. In the same year, a decision was made to use the northern section of the tailings dam as a low-level radioactive waste disposal (see section 3.4.6 — Low-Level Radioactive Waste Repository), with the last deposit being made in 1998. More detail relating to the tailings impoundment is provided in section 3.4 (Waste Management and Disposal Practices).

3.3.6.1 PRESENT STATUS

Recent site visits indicate that the tailings impoundment appears structurally sound and have a good natural re-colonisation of vegetation (Fig. 16).

Fig. 16 *Vegetation on top of main Radium Hill tailings impoundment, looking from the centre towards the mine, 2004. (Source: PIRSA 049704)*

3.3.7 WASTE ROCK DUMPS

Waste rock extracted from the mine was largely placed to the south of the mill site (Fig. 17). This area also included the excess heavy-media rejects not railed offsite for ballast.

During operations and following decommissioning of the site, the practice of using this material for road and possibly rail construction or maintenance continued through, it is believed, until the early 1980s.

In addition, it is believed that a large quantity of this material was used for backfilling purposes during and after mining operations to seal openings etc. More detail relating to the waste rock material is provided in section 3.4 (Waste Management and Disposal Practices).

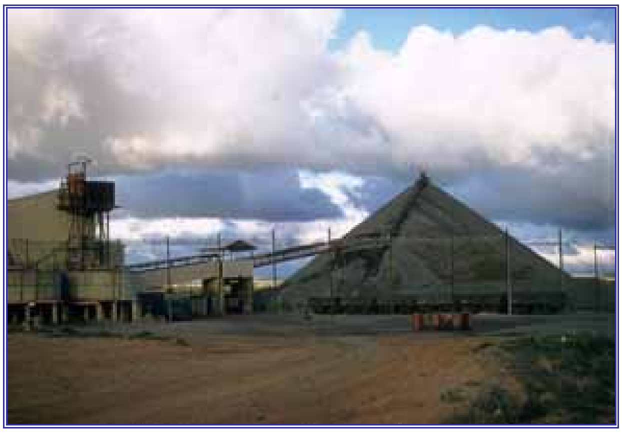


Fig. 17 *Portion of the Radium Hill waste rock dump area and heavy media separation pile, 1950s. (Source: PIRSA T04488)*

3.3.7.1 PRESENT STATUS

Because of ongoing disturbance (at least till the mid-1980s) to the original waste-rock piles, much of the material appears to have been crushed and/or screened and/or relocated to various parts of the mine area, or relocated offsite (Fig. 18). For further information, refer to section 3.4 (Waste Management and Disposal Practices).

Fig. 18 *Waste rock and reject pile area, looking north towards the former Radium Hill mill and ore bins, 2004. (Source: PIRSA 049703)*

3.3.8 TOWNSHIP

A township to support 1100 people was built (Fig. 21), with water being piped from NSW, a railway spur constructed to connect Radium Hill with the Broken Hill – Port Pirie line, and a power transmission line constructed from Morgan. Between 1949 and 1952, the Housing Trust built 145 houses, many prefabricated. A population of 867 was recorded at the township in 1961. The residential area comprised houses (Fig. 19), a hospital, school, government retail store, canteens, swimming pool, and other support, recreational and commercial facilities.

Fig. 19 *Radium Hill township looking easterly towards the water tank on the hill, in the 1950s. (Source: PIRSA T022449)*

3.3.8.1 PRESENT STATUS

Virtually all buildings etc. were removed or demolished during decommissioning of the mining operation. Foundations, garden sites etc. remain as visible reminders for many of the former residences and support buildings. The area around the school site is used as a campsite for visitors and members of the Radium Hill Historical Association; these same people are largely responsible for upkeep of the town cemetery (Fig. 20) located to the northwest of the town site.

Fig. 20 *Radium Hill pioneers cemetery, 2004. (Source PIRSA 049700)*

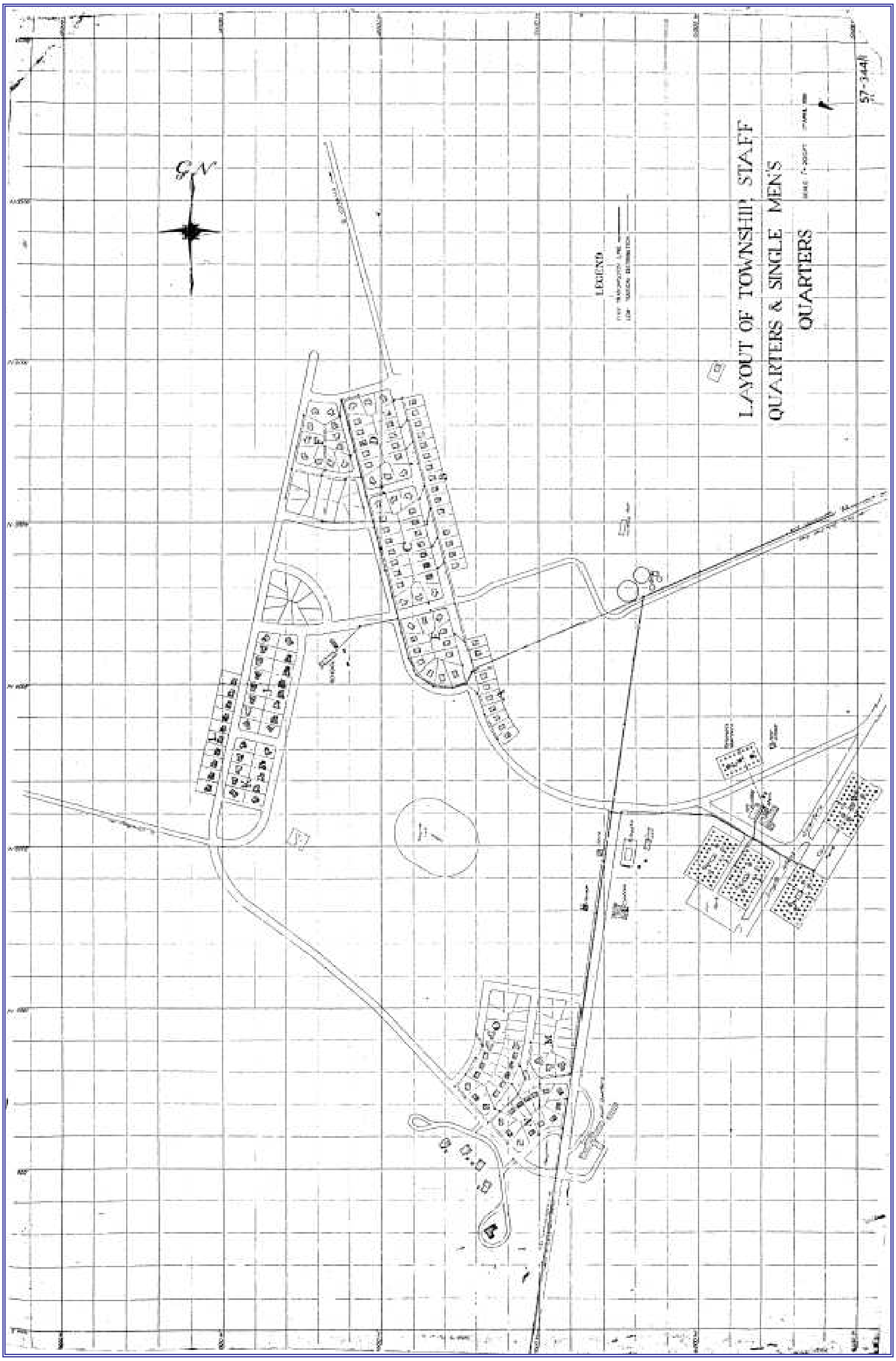


Fig. 21 *Radium Hill township layout, 1957 (Source PIRSA 57-0344).*

3.3.9 REGIONAL WORKINGS

Previous to, during and following mine development, operation and decommissioning, a large amount of exploration was undertaken throughout the area to prove up additional resources, resulting in a large number of costeans and drillholes being constructed.

3.3.9.1 PRESENT STATUS

Throughout the Radium Hill area, a number of exploratory related disturbances are visible, mainly open costeans (Fig. 22), drillholes and associated refuse; these are all in varying states of natural restabilisation and revegetation.

Fig. 22 *8000N costean at Radium Hill, 2003 (Source PIRSA 049694)*

3.3.10 WASTE DISPOSAL AREAS

Other than the main waste process streams that resulted in the formation of the tailings and waste rock areas, mine-related and domestic refuse was disposed of within the surrounding area, generally within near-surface excavations (Fig. 23). Further details are supplied in the following section.

Fig. 23 *Radium Hill rubbish dump, 2003 (Source PIRSA 049705)*

3.4 WASTE MANAGEMENT AND DISPOSAL PRACTICES

3.4.1 NON-RADIOLOGICAL CONTAMINANTS

Whilst the main focus of the Radium Hill site and this report is on the radiological environment, other processes would have resulted in potential contaminants being present, with the possibility of these still being in existence today. Looking at the various functional areas of the site again, Table 5 provides a guide as to the possible contaminants that may be present within each area, although no testing has been undertaken to confirm their presence.

Table 5 *Potential contaminants within the Radium Hill area.*

Area description	Hydrocarbons and fuels	Asbestos	PCBs	Explosives	Pyrophoric wastes	Heavy metals	Solvents	Organic chemicals	Inorganic chemicals
Mine workings				✓		✓			
Mine surface infrastructure area			✓						
Mill and treatment area	✓	✓				✓	✓	✓	
Support buildings area	✓	✓					✓	✓	✓
Support infrastructure areas	✓		✓						
Tailings impoundment area						✓		✓	✓
Waste rock dumps						✓			
Township		✓							
Waste disposal areas	✓	✓	✓	✓	✓		✓	✓	✓

3.4.2 RADIOACTIVE MINE-WASTE PHASES

Radioactive wastes may have arisen from all phases of the mining operation including the exploration of the site, development, construction, and operation and decommissioning of the mine and mill facilities, rehabilitation of those facilities, and associated radioactive waste residues.

3.4.2.1 EXPLORATION

Exploratory activities for radioactive ores have been carried out within both the local and regional Radium Hill environment since the initial discovery of davidite in 1906. These activities included the sinking of shafts, drilling of boreholes, costeaning, and various other methods to gain access to known and potential radioactive mineralisation located throughout the area. In addition, it is known that other than the pre-1952 operations, at least one pilot plant was set up within the general mine area to test the recovery of these ores prior to full-scale operations commencing.

3.4.2.2 DEVELOPMENT

The main stage of development in the Radium Hill area commenced in 1952 when the sinking of major portals was undertaken to access the ore. Upon extraction, waste rock from the mine workings was largely placed to the south of the mill site. It is known that this material was also used in the construction of roads and foundations in a number of areas along the connecting rail system. During the 1960s, large amounts of waste rock and rubble from the site were used for ballast during the standardisation of the railways.

3.4.2.3 OPERATION

As early as 1909, the first operational mine had been set up (largely to extract radium) immediately to the west of the main 1952–61 workings. A concentrator was set up on site to pre-process this ore before being sent to Sydney for smelting and further treatment. During the 1952–1961 operations, a number of waste streams resulting from the extraction, transport and deposition process pathways can be followed. The two main residues resulting from these operational phases (other than waste rock) were reject material from the heavy-media separation section (this was either stockpiled immediately south of the mill or loaded directly by conveyor to rail truck to be used for ballast), and tailings resulting from the flotation section which were delivered hydraulically to the tailings impoundment.

3.4.2.4 DECOMMISSIONING

During decommissioning of the mine, most of the associated infrastructure was demolished and/or removed from site for further use. Quantities of the coarse mullock were also used in the filling and closing of many of the mine openings during decommissioning.

3.4.2.5 REHABILITATION

During rehabilitation activities, residues have been moved and/or further disturbed by various operations and processes, including covering and containment (refer to Chapter 5 for further details).

3.4.3 WASTE-ROCK DUMP AREAS

This area includes both waste-rock from the mine and reject material resulting from the heavy-media separation plant (Fig. 27).

3.4.3.1 OPERATIONAL PHASE

Waste rock from the mine workings was largely placed to the south of the mill site. It is known that this material was also used in the construction of roads, foundations and as ballast in a number of areas along the connecting rail system during the various phases of the mine life, including:

- Initial requests being made in 1953 to use both heavy-media separated reject material and waste rock for construction purposes at the mine area, and to lay road and building foundations for the township. Due to uncertainties as to whether this material could be reprocessed at a later date, the request was initially declined. However, approval was later granted in 1954 for use in aggregate, and in 1955 for use in road works within the area SR14/1/4. As a result of this material being used for these purposes, areas of elevated radiation in the townsite and associated roads are clearly indicated in Figures 25 and 26.

- In 1956, a recommendation was made by the Mines Department to sell heavy-media reject material for ballast following requests from the South Australian Railways. At that time, tailings were being produced at a rate of 100 000 t/year and had a U_3O_8 content of 175 g/t. It is believed that this was used mostly along the sections between Olary and Cockburn (SR 14/1/4). Refer to section 4.2.2.1 for relative radiation levels recorded along some portions of this line where the ballast material was used.

- Heavy-media reject material was purchased from 1957 onwards for use in road construction by the Highways and Local Government Department. It is believed to have included screenings used along the Broken Hill road when it was sealed from Cockburn (O'Neil, 1995, p.224). A report from July 1963 also indicated that:

  > 'At present the Highways and Local Government Department has a contractor, … screening the 'mixed material' on Mt. Nelson, and substantial dumps of screenings have been established alongside the Industrial area; at MacDonald's Hill siding, and at several points along the road towards Peterborough.' (DM 2017/61)

3.4.3.2 DECOMMISSIONING AND REHABILITATION

At the time of decommissioning, the waste-rock dump and heavy-media rejects area were surveyed and estimates made of the volume of material (Table 6). Following decommissioning of the site, the practice of using this rock material for road and possibly rail construction continued through, it is believed, to the early 1980s. In 1985, a request by the Highways Department to remove sand(?) from the site was not approved by the Mines Department (SR 5/6/48/9/9) and it is believed that no further removal of material has occurred since. Much of the coarse rock has been moved over various periods following decommissioning to place into a number of open stopes and along the line of lode (Fig. 24) where subsidence was considered possible.

Fig. 24 *Waste rock material along the line of lode at Radium Hill, looking from the old mine shaft towards the main shaft to the right of picture, 2003 (Source PIRSA 049695)*

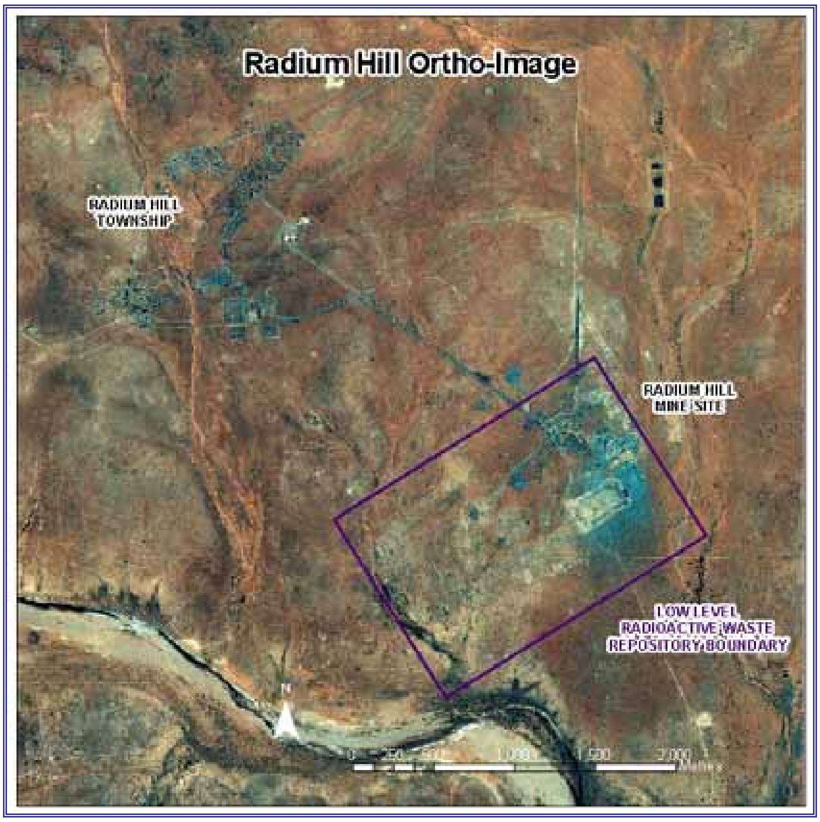


Fig. 25 *Radium Hill orthophoto. (Source PIRSA)*

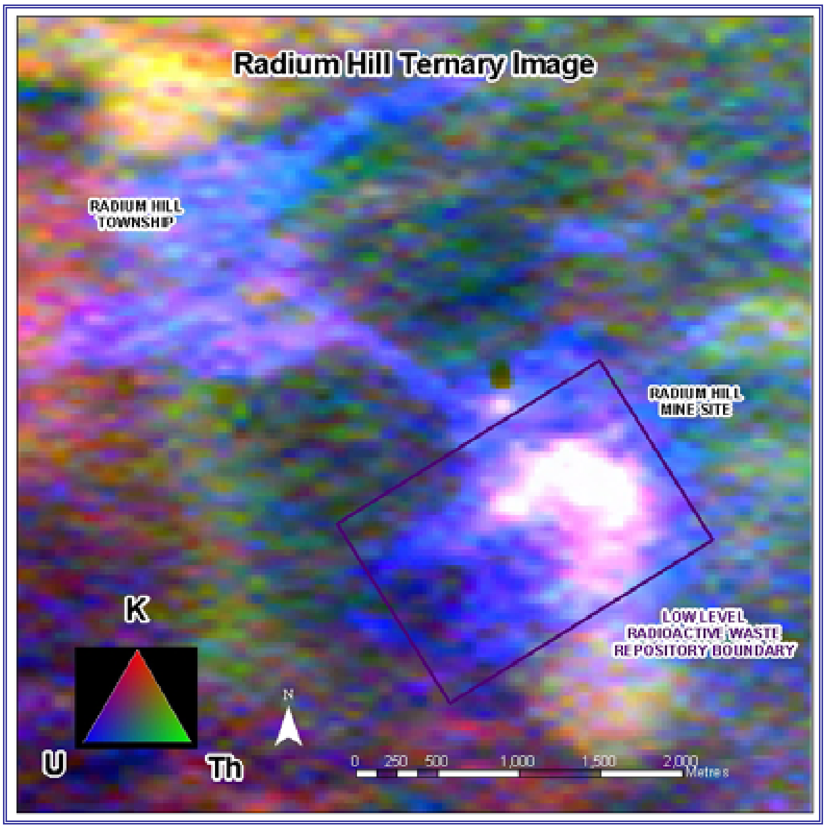


Fig. 26 *Radium Hill combined radiometric image. (Source PIRSA)*

The most recent quantitative estimate of waste rock is believed to be from an assessment made in 1981 to determine suitable quantities of material that could be used as gravel armour over the tailings impoundment during rehabilitation. Armouring was not carried out, however, due to the additional cost. Most of these gravel piles remain today (see Fig. 28) and include:

- two rectangular stockpiles south of the mill site containing 7400 m³ of 3–6 mm fine crushed gravel (1–2 µSv recorded in 2004) — sites (1) and (2)
- one stockpile immediately south of the mill where the former rail-loading facility was located, containing 1000 m³ of 50 mm coarse gravel — site (3)
- one stockpile to the east of the mill containing 1000 m³ of 3 mm fine crushed gravel — site (4)
- one rectangular stockpile east of the road to the living quarters north of the mine, containing 500 truck loads (2500 t) of 3–6 mm fine crushed gravel (1.5–2.0 µSv recorded in 2004) — site (5).

(Author's note: based on photo-interpretation, it is believed the estimated quantities from 1981 underestimate the quantity of material present by a factor of three, e.g. the area showing 2500 t has been re-calculated to be 8400 t utilising GIS).

Table 6 *Estimated volume and tonnage of waste rock and heavy-media material at Radium Hill.*

Area	Cubic metres 1962	Tonnes based on a nominal bulking factor of 1.6 1962	Estimate of remaining material 1981 (t)	1981 figures multiplied by factor of 3 2004 (t)
Large dump	150 230	240 400		
Mt Nelson	54 200	86 700		
Scattered dumps	4 200	6 700		
Total	208 630	333 800	23 200	75 000

Fig. 27 *Portion of the waste-rock dump area and heavy-media separation piles at Radium Hill in the 1950s. The large pile is often referred to as Mt Nelson. (Source: PIRSA T004524)*

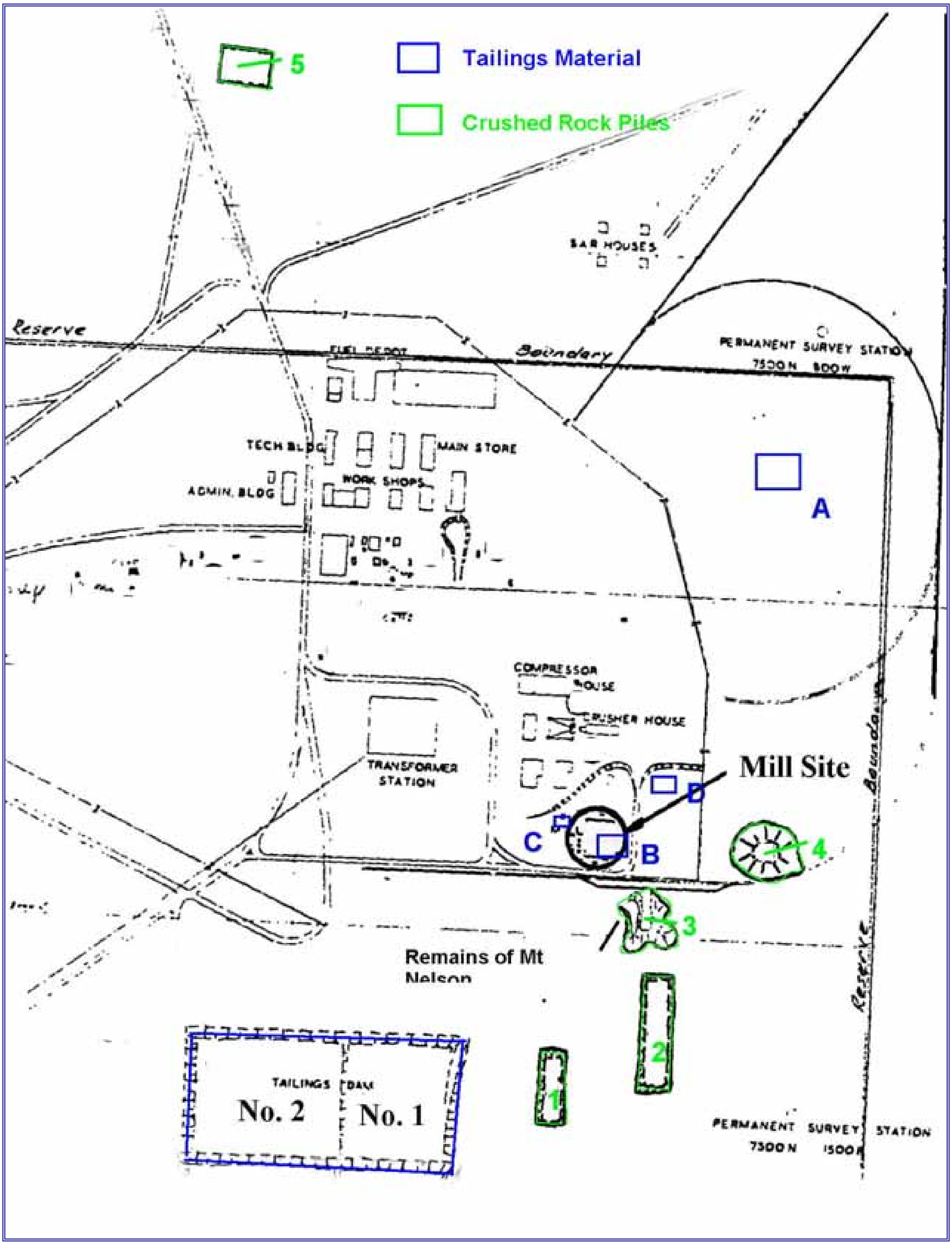


Fig. 28 *Radium Hill tailings piles, waste rock and heavy-media reject dumps. Original 1962 plan. (Source PIRSA)*

3.4.4 TAILINGS IMPOUNDMENT

3.4.4.1 OPERATIONAL PHASE

Originally, the mill tailings were disposed of (presumably to the main tailings impoundment area) after filtration to recover water. This method was considered at the time to be economically viable despite the comparatively large expenditure in pulp holding tanks, filters and accessory equipment, and the additional building space required. This was considered a novel feature of the mine, although after a year's operation this was discontinued and the more conventional means of disposing tailings to the impoundment was initiated.

The major tailings resulting from mining operations at the Radium Hill site are located in the impoundments consisting of two sections each approximately 125x125 m (Fig. 29). Based on the 1966 AMDEL report and departmental correspondence, these dams contain about 225 000 t of tailings averaging 0.000325% U_3O_8 and 0.006% Sc_2O_3.

3.4.4.1.1 No. 1 Tailings Impoundment

The No. 1 tailings impoundment (122x122 m x5.5 m high) was reported to contain approximately 109 000 t, of which the first 72 500 t laid down averaged 0.000475% U_3O_8 and 0.008% Sc_2O_3, while the top 36 500 t laid down after changes in the treatment method averaged 0.00025% U_3O_8 and about 0.006% Sc_2O_3.

The average sizing of the tailings in impoundment 1 are:

+0.25 mm	6.3%
-0.25→+0.15 mm	18.1%
-0.15 mm→+0.105 mm	19.3%
-0.105 mm→+0.074 mm	13.3%
-0.074 mm	43.3%

3.4.4.1.2 No. 2 Tailings Impoundment

The No. 2 tailings impoundment (122x122 m x6.1–7.0 m high) probably contained over 118 000 t of material assaying nearly 0.00025% U_3O_8 and 0.005–0.006% Sc_2O_3.

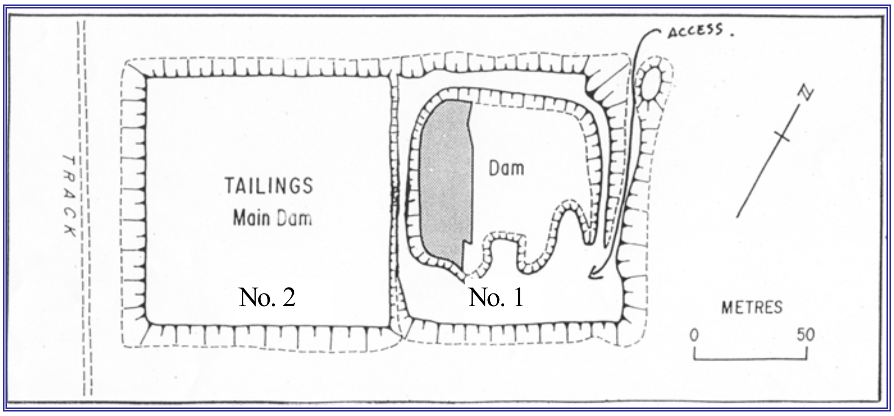


Fig. 29 *Radium Hill tailings impoundment (prior to cover placement), circa 1962. (Source PIRSA)*

3.4.4.1.3 Other Tailing Areas

A number of smaller piles of tailings have been located over the years, possibly related to trial plants etc., but in most instances these have either been subsequently removed or covered.

From a file note in 1981 (SR5/6/129), the following details were reported in relation to a number of additional tailings piles (Fig. 28):

- pilot plant tailings impoundment located approximately 400 m northeast of the plant site; the tailings are covered — site (A) on Figure 28
- 'Kevin Carter' heaps (2) near the mill site (Fig. 30); the tailings are covered — sites (B) and (C)
- 'A Johnston' heap, possibly mill spillage, 80 m northeast of 'Kevin Carter' piles. Left as is? — site (D)

Fig. 30 *'Kevin Carter' tailings pile, prior to covering, 1981. (Source PIRSA 049698)*

3.4.4.2 DECOMMISSIONING AND REHABILITATION

Consideration was given during the decommissioning period to placing the tailings materials back into the workings but this was not done. It is believed that at the time of decommissioning only the main tailings impoundment was partially protected by rock material, but this has not been verified. The minimal covering of the tailings impoundment resulted in erosion of the walls and dispersion by wind and water of the tailings material to the surrounding area (Fig. 31). In 1981, a decision was made to rehabilitate the impoundments with a cover of soil using material from four adjacent borrow pits (Fig. 32). The earthworks required for this were managed and completed by the former South Australian Engineering and Water Supply Department (E&WS, now Department of Water, Land and Biodiversity Conservation). The decision not to armour the tailings heaps with rock material was due to financial restrictions at the time. Approximately 75 000 m^3 of material was used during construction of the covers.

Fig. 31 *Radium Hill Mine tailings prior to remediation, 1980 (Source: PIRSA 045766)*

In 1981, a decision was made to use the smaller (No. 1) mound of the tailings impoundment as a low-level radioactive waste disposal site (see section 3.4.6 — Low-Level Radioactive Waste Repository), with the last deposit being made in 1998.

Fig. 32 *Similar view to Fig. 31, following rehabilitation (in 1981), 2002. (Source: PIRSA 049696)*

Much of the presently exposed tailings material at the base of the impoundments originally thought to have been windblown has in fact accumulated from erosive actions to the impoundments prior to their covering in 1981 and also due to spillage during operational placement as evidenced by photos from the main mine working period (1954–61).

3.4.5 OTHER MINE-RELATED WASTE

During the decommissioning process, much of the structures etc. were sold either whole or recycled. Arrangements were made that all productive operations would cease on 22 December 1961, and full salvage began on 2 January 1962. Disposal operations continued until about 1964 with the removal of water, rail and powerlines.

A report dated May 1962 indicated that drill core and all junk material was to be dumped in Smith Shaft (DM 2017/61). It is uncertain that this was carried out at the time, however during rehabilitation of the tailings impoundment in 1981, it was recorded that a pile of drill cores and general scrap metal rubbish from the old mill area was collected and buried, presumably within the repository area.

3.4.6 LOW-LEVEL RADIOACTIVE WASTE REPOSITORY

On 2 April 1981, an area 'Reserved for purposes of a repository for low-level radioactive materials' was gazetted. This same area was first gazetted on 28 August 1975 as 'Radium Hill Lands — Reserved from the operation of the Mining Act'. The gazettal notice was made under the Crowns Land Act, and vests care, control and management of the site with the Minister of Mines and Energy.

This particular site was selected for the following reasons:

- the site contains enhanced radioactivity due to mineral occurrence of a similar nature to the low level waste
- the area was an existing disturbed land site
- the area is a low rainfall area with no significant groundwater resource
- the site is relatively geologically stable
- the location is remote, reducing potential exposure to the population
- the site was under existing government control

(K. Griffith, DPC, written. comm., 2001 (Draft))

3.4.6.1 INVENTORY

Since 1981, the repository has received a number of deposits of low-level radioactive waste, with the last deposit being made in 1998. The general policy was that loose material would not be buried within the repository (MO 7033.001), but rather into the surrounding borrow pits (the moat) and other areas, e.g. along the line of lode. From PIRSA records, there are approximately 230 m^3 of material located within the repository (Table 7). Appendix 5 provides known details of material and location of the various deposits; these have largely come from the AMDEL laboratory (Thebarton, Adelaide), and mineral cores etc. from various exploration projects.

***Table 7** Material deposited into the low-level radioactive waste repository at Radium Hill.*

Date of disposal	Container type	Container volume (L)	Number of containers	Total volume (m^3)
February 1981	Drum	200	140	28
March 1981	Drum	200	660	132
March 1981	Drum	20	167	3.34
June 1982	Drum	200	56	11.2
June 1982	Drum	20	128	2.56
September 1982	Drum	200	23	4.6
April 1983	Drum	200	57	11.4
April 1983	Drum	50	5	0.25
April 1983	Drum	20	80	1.6
April 1983	Misc	–	–	–
April 1985	Drum	200	80	16
August 1986	Drum	200	32	6.4
August 1986	Drum	20	9	0.18
September 1986	Drum	200	16	3.2
July 1998	Drum	200	63	12.6
			Total	**233.33**

3.5 CHAPTER SUMMARY

The Radium Hill area was first mined in the early 20th century for radium, but these early attempts were largely unsuccessful, and it was not until 1954 that a full-scale mining operation was initiated to produce uranium. This full-scale operation was commissioned and operated by the South Australian Government to satisfy a contract signed by the Commonwealth and SA Government with the UK–USA Combined Development Agency for delivery of uranium over a seven-year period. On completion of the contract, the mine was decommissioned, access to mine workings was blocked, and infrastructure was removed to the environmental standard of the day.

Little remains of the 1954–61 operations other than a number of foundations, infrastructure remnants, tailings impoundment and some waste rock and heavy-media reject piles. Even less evident are the various operations prior to this period when the main commodity of interest was radium. In addition to the resultant 'footprint' of the main mining operations, extensive areas have been disturbed due to numerous exploratory activities within the general vicinity of the mine.

The marked contrast of the grey-coloured waste rock and tailings material to the surrounding red-brown colour of the background environment is considered to be one of the major visual impacts of the site, and may not realistically reflect the relative radiological and/or chemical impact.

On 2 April 1981, an area 'Reserved for purposes of a repository for low-level radioactive materials' was gazetted. This repository received approximately 16 separate consignments of low-level radioactive waste from that time until the last deposit in 1998.

CHAPTER 4 — SITE CHARACTERISATION

4.1 INTRODUCTION

Together with information derived from the 'Site Description', further information is often required in a number of instances on more specific issues in order to provide a greater understanding of the site's explicit characteristics.

4.2 RADIOLOGICAL ENVIRONMENT

4.2.1 OVERVIEW

Information relating to the radiological structure of uranium ore and tailings resulting from mining operations at Radium Hill are presented in Appendix 3.

The Radium Hill area displays enhanced radioactivity and always will, due to the mineralised ore intersecting the surface. The ridge along the strike of the mine had readings as high as 14 μGy/hr and the general background around the mine was 0.5–1 μGy/hr (SR 5/6/48/8/1).

Other than ground and airborne radiometric surveys for the purposes of exploration and development of the resource, no other recordings have been located of specific radiological conditions, e.g. radon emissions, groundwater radionuclides etc. prior to establishment of the mine.

4.2.2 GAMMA DOSE RATE

The *Radiation Protection and Control (Ionising Radiation) Regulations 2000* set a limit not exceeding 1 milli sievert (mSv) as an annual effective dose to a member of the public. Based on this figure, the limit for continuous exposure (e.g. 12 hours a day, every day of the year) to members of the public would correspond to about 0.2 μGy/hr.

The following measurements (Tables 8–10) were taken during a number of visits conducted between 1981 and 2004, and recorded on a random basis throughout the area. Note:

- these tables are not presented as a comparison between the various years as no georeferenced coordinates were used for repeatability purposes; they are presented to demonstrate the similarities that may be obtained between the same locations
- the 1998 gamma readings were originally recorded in μSv/hr, however, for the purposes of this report, they have been converted to μGy/hr using a quality factor of 1 for gamma radiation.

Table 8 *Gamma readings, Radium Hill, 2004; see Plan 2 for locations shown in brackets (readings undertaken by M. McLeary (PIRSA); the instrument used was a Nuclear Enterprises PDR1; measurements taken at waist height unless otherwise specified.).*

Site	µGy/hr
General area approximately 100 m from workings etc.	~ 0.1
Mullock piles over former whip shaft (F)	0.5–1
Mullock piles (peak) near former whip shaft (F); specimen of ore	12 (contact)
Mill site	0.5–2
Mill site (peak) near small concrete tower	10
Around main ore pass (W)	~2
Tailings dump area — screenings etc.	1–2
Top of tailings impoundment (No.1) (slimes)	0.2–0.3
Top of repository	~0.3
Windblown(?) tailings — fines immediately east of impoundments	Up to 1.5
Windblown tailings fines surrounding the impoundments	~0.5
Screenings approximately 300 m north of the main mine area	1.5–2.0

Table 9 *Gamma readings, Radium Hill, 1998 (readings undertaken by M. Sonter using a Rotem gamma monitor).*

Site	µGy/hr
On covered top section of tailings impoundment	0.2–0.25
On lower bench section of tailings impoundment	0.45 max
On screens stockpiles	1.5
On drifts of windblown fines	0.75–1.0
Mineralised gravel on road	0.35–0.4
Rock dumps along line of lode	0.5–0.7
Approximately 100 m north of the line of lode	0.17

Table 10 *Gamma readings, Radium Hill, 1981.*

Site	µGy/hr
Mine area background readings	0.35–0.7
On top of the tailings before covering	0.42–0.7
On top of the tailings after covering	0.07–0.28
Above buried drums of waste	0.75–1.0

4.2.2.1 RADIATION LEVELS (BALLAST MATERIAL)

Whilst not located within the boundaries of the Radium Hill site, it is known that rock material originating from the mine was used for ballast on the Broken Hill railway. Readings (SR5/6/129 vol.1) of railway ballast recorded at 10 km intervals along the Cutana Siding to Cockburn section of the Broken Hill line are presented in Table 11. Similar comparisons related to the recorded gamma measurements can be made with ballast material sourced from granitic rock material.

***Table 11** Gamma dose readings of ballast material. (Source PIRSA)*

Distance from Adelaide (km; railway posted)		Background (Avg.) (µGy/hr)	Ballast (Avg.) (µGy/hr)
Cutana	444	0.12	0.35
	454	0.065	0.22
	464	0.07	0.3
	474	0.075	0.2
Cockburn	483	0.08	0.03

Note: Measurements were taken at waist height using a Studsvik Gamma meter 2414A (SR 5/6/129 vol.1)

4.2.3 RADON

No details relating to radon emissions from the workings or waste material have been located.

4.2.4 RADIOACTIVE DUST

> In order to determine radioactive exposure from dust, a complete analysis is required including determining size particles, and chemical and radionuclide composition. At the time the following samples were taken (early 1980s), the recommended limit for long-term exposure to uranium ore dust was 1.3 Bq/m^3. However, this scenario does present a 'worse-case exposure' and would be applicable if the tailings were interfered with on a large scale.

Dust samples were collected and measured during rehabilitation of the main tailings impoundment in 1981. A report by Crouch (1981) contained the following:

'The concentration of radioactive dust in air was measured on three occasions. On the first, the dust would not adhere to the polycarbonate filters used for sampling. This was remedied by the use of glass fibre filters for subsequent sampling. On the second occasion, dust concentrations were measured during the unloading and burying of drums of uranium tailings. Dust concentrations reached 3.2 Bq/m^3. On the third occasion, during covering of the top of the tailings pile, dust concentrations reached 1.3 Bq/m^3. The recommended limit for long-term exposure to uranium ore dust is 1.3 Bq/m^3. However, as all employees wore respiratory protection whenever tailings material was disturbed, no one was exposed to these concentrations of radioactive dust.'

4.3 HYDROLOGICAL ENVIRONMENT

No recent testing of hydrological conditions or chemical water analysis has been undertaken. A water sample of the Radium hill Mine water taken in 1958 from the 4600N shaft located in the South Hill Extension yielded the following analysis:

Cations	**mg/L**	**Hardness**	**mg/L**
Ca	762.5	Hard	5726
Mg	926.7	**Nutrients**	**mg/L**
Na	5706.2	NO_3	51.4
Anions	**mg/L**	**Other**	**mg/L**
SO_4	3732.7	CO_3	162.7
Cl	9871.7		

4.4 GEOCHEMICAL AND MINERALOGICAL ENVIRONMENT

Davidite, the main ore mineral, is a highly complex iron–uranium titanate associated with ilmenite, magnetite, rutile, haematite, quartz and biotite.

The composition and description of davidite are as follows, with more detailed information supplied in Appendix 9.

Davidite (La)

Formula: $(La, Ce)(Y, U, Fe)(Ti, Fe)_{20}(O, OH)_{38}$

System: Trigonal	Colour: Black
Lustre: Vitreous	Hardness: 6
Density: 4.42	Streak: Brownish black

(Source: The Mineral database and The Mineralogy database)

The host rock mined to access the ore is commonly referred to as gneiss, but schist was also present. Gneiss is coarser than schist and has distinct banding. Gneiss is composed of the similar minerals to granite, with feldspars, mica and quartz being the most important.

A study into mine dust and related occupational exposures at the Radium Hill site by Wilson (1996) reported the following in relation to the mineralogy of the ore and associated mullock material:

The minerals that comprise the building blocks of Davidite have the following properties:

- Ilmenite ($FeTiO_3$) — 52.65% titanium, 47.4% ferrous oxide, minor uranium dioxide
- Titanium (Ti) (SG 4.5)
- Iron (SG 7.86)
- Uranium, metallic (SG 19), uranium oxides (SG ~9.0–9.3).

Other minerals in the ore zones and mullock include:

- Micas (SG 2.8–3.1), comprising muscovite 2.8–2.9 and biotite 3.0–3.1, occur as particles and also books of cleavable sheets up to 1 m in diameter.
- Hornblende (SG 3.2–3.5)
- Feldspars (S.G 2.56)
- Quartz (SG 2.66).

4.5 STRUCTURAL ENVIRONMENT

The structural environment relates to man-made structures etc. built onsite as part of the various operations and phases undertaken over the years since the mine site was initially established, and includes buildings, tailings impoundment etc.

4.5.1 STRUCTURAL INTEGRITY

4.5.1.1 TAILINGS IMPOUNDMENT

In October 1996, Assoc. Prof. R.J. Jewell of the Australian Centre for Geomechanics visited the tailings impoundment at Radium Hill and indicated that 'Without additional hard data that could only be derived from more comprehensive investigations at each site, I believe that both storages [referring to Port Pirie and Radium Hill sites] are currently safe and stable and in absence of some unforeseen event are likely to stay so for some time into the future.' (R. Jewell, ACG, pers. comm., 1997).

The following are extracts from the field observation report:

'The storage is currently totally covered by soil borrow and, with the exception of minor slope erosion on one face, is in sound condition.'

'Currently, the trenches from which the soil was borrowed surround the facility on three sides and provide some protection, should the capping breach. At the time of the visit, natural revegetation had been re-established on the top and sides of the storage facility and, apart from its profile, it would be difficult to distinguish from the surrounding scrub.'

'The tailings in their current form are stable and with some further work to ensure that erosion of the side slopes does not take place, they should remain stable into the future. The side slopes appear steep and, although they are reasonably low in height, there could be the potential for some continuing erosion in this area. It may be necessary to protect the slope armouring, if protection against scour has to be ensured into the future.' (Jewell, 1996)

Note: Some minor remedial work was undertaken shortly after this date because of these recommendations.

4.5.1.2 UNDERGROUND WORKINGS

Whilst many of the original underground workings have been backfilled using existing waste rock, a number of former mine shafts have been capped with concrete pads and/or plugs. A report in August 1962 from the then Director of Mines indicated 'the area is considered safe at present and will be inspected regularly'. In July 1963, a further report indicated that 'several minor shaft subsidence's have occurred, probably due to very wet weather, and these will have to be filled in…it is expected subsidence's of this nature may continue for several years at least' (DM2017/61).

Appendix 7 details each of the mine openings and provides information on known closure structures and methods (converted to metric units), together with a surface assessment of these openings undertaken by PIRSA Mines Inspectors in 2001.

4.5.1.3 BUILDINGS AND STRUCTURES

The only remaining structures around the former mine site (other than foundations) are the two ore bins near the mill site and part of the crusher building and hopper. Within the vicinity of the township, some remains of walls are in evidence from a number of the former residences and commercial buildings, the swimming pool and water reservoir.

4.6 CHAPTER SUMMARY

Limited information has been collected over the years subsequent to the main operational period of 1954-1961 in order to characterise the site's radiological, hydrological, geochemical, mineralogical and structural environments.

Whilst no definitive radiological studies have been undertaken in recent years, random sampling from the area indicates elevated gamma levels on areas of waste rock and mill tailings together with those areas where waste rock has been used during development and operation of the former mine.

An initial structural assessment of the tailings impoundment has indicated it is 'currently safe and stable and in the absence of some unforeseen event are likely to stay so for some time in to the future' (R. Jewell, ACG, pers. comm., 1997). However, the structural integrity of the underground workings and entrance portal covers and plugs is unknown.

CHAPTER 5 — MANAGEMENT AND REMEDIATION

5.1 SITE MANAGEMENT

Site inspections are carried out on a semi-regular basis at Radium Hill by PIRSA employees to review the condition of existing structures and containment areas.

Examples of recorded inspections undertaken since 1998 (the year of the last deposit of material to the waste repository) are briefly outlined in Appendix 4, however it should be noted that numerous other visits by PIRSA staff and others have been undertaken to record and/or study geological conditions etc.

5.1.1 SITE SECURITY AND ACCESS

The aim of any site security measure is to minimise and/or control the exposure to potential risks.

5.1.1.1 ACCESS AND PROMOTION

Radium Hill is considered a remote site, located approximately 25 km by road and track from the main Barrier Highway. Whilst four-wheel-drive vehicles are not required to access the site, conventional vehicles are not generally suitable due to their low ground clearance.

In January 2004, a site visit noted that although the track showed signs of minor water erosion in a number of places, it did not impede travel to any great degree. The property owner from Tikalina Station also indicated that he would be grading the road as requested by PIRSA within the following month.

The Radium Hill site is not actively promoted by any government (local, state or federal) and, in most instances, requests to access the site are generally discouraged. However, it is known that members of the Radium Hill Historical Association and the public do occasionally visit the area throughout the year. Extended periods of stay (i.e. overnight minimum) within the general area are normally limited to the area of the Radium Hill township.

Although the State Government's policy is to minimise its public liability risks by not actively encouraging visitors to the site, a concession was made in the case of the Radium Hill Reunion Committee (now Radium Hill Historical Association) regarding access to the cemetery and township. In return, the association was requested to not publicly advertise or promote visits to the site. Generally, tourism has a low profile in this district.

5.1.1.2 SECURITY

Although the site is not monitored on a continual basis, inspections are generally undertaken at least once per year by PIRSA staff to check the condition of roads, signage, structures, impoundments, mine workings etc.

Other than general fencing for the purposes of grazing, the only feature fenced within the Radium Hill Repository is an area near the old mill site considered unstable due to potential ground movement above some of the underground workings.

Australian Standard AS 1319-1994 sets out design and use standards for safety signs used in the occupational environment. Safety signs are classified by function into various groups.

Within the Radium Hill site, warning signs (Fig. 33) are placed in strategic positions around the area of the tailings impoundment warning of entering the 'Low-Grade Radioactive Residue Disposal Site'.

Fig. 33 *Current signage warning of low-grade radioactive residue disposal site, 2003. (Source PIRSA 049702)*

In addition, signs warning of 'ground subsidence' are placed along and within the fence surrounding the area of subsidence near the former main shaft.

It was noted in the 2004 visit that many of these subsidence warning signs are in need of replacement due mainly to fading. It was also noted that repairs are required to the fence surrounding the area of unstable ground.

5.1.2 STRUCTURAL CONDITION

The structural condition of remnant buildings and impoundments are inspected as a matter of course during site visits by PIRSA personnel, however this is not generally done on a methodical or systematic basis. Where minor repairs are required, this is generally undertaken shortly after notification. In a visit to the site in January 2004, other than a brief view of surface conditions surrounding a number of these sites, no formal structural assessment was made.

5.1.3 DEPOSITION OF LOW-LEVEL WASTE

Although no further deposits of low-level radioactive waste have been made at the Radium Hill Repository since 1998, a draft guideline has been developed to ensure that procedures are authorised, detailed and supervised (see Appendix 8).

5.2 LONG-TERM MANAGEMENT

The Commission on Geosciences, Environment and Resources (2000) provides a conceptual framework for sites that may require management over extended time periods whereby the long-term institutional management of contaminated sites should be: Long-term institutional management of contaminated sites should be:

- **realistic** in being based on recognition of practical constraints as well as capabilities;
- **systematic** in its overall approach; and
- **integrative** and **comprehensive** in its consideration of three measures:
  1) the types of **contaminant reduction** measures employed;
  2) the types of **contaminant isolation** measures employed; and
  3) the reliance placed on **stewardship** measures,

so that the balance achieved among reliance on each of these three types of measures is appropriate given the following contextual factors:

- risks to members of the public, workers and the environment;
- technical and institutional capabilities and limitations, and the current state of scientific knowledge;
- costs and related budgetary considerations;
- legal and regulatory requirements;
- values and preferences of interested and affected parties; and
- impacts on other sites. (CGER, 2000 p.18).

5.2.1 FINAL LAND USE

The Radium Hill site has limited potential future land uses due to a number of fundamental characteristics including:

- natural elevated background radiation levels
- remoteness from existing and likely future population centres
- aridity
- low relief
- saline groundwater.

5.2.2 FUTURE MINING POTENTIAL

ESSO Exploration and Development Incorporated re-evaluated the Radium Hill deposit in 1981 and reported that the resources, largely below previous mining which extended as deep as 290 m, were insufficient to warrant further consideration. The remaining mineral resources below the old mine workings were estimated to be 890 000 t averaging 0.009% U_3O_8 (Yates, 1992).

Requests from a number of companies to test tailings material within the main tailings impoundment for rare earths etc. have generally been discouraged due to potentially impacting on the impoundment's structural integrity.

5.3 REMEDIATION

5.3.1 PREVIOUS REHABILITATION AND CLEANUP ACTIVITIES

Immediately following mine decommissioning, rehabilitation of the site largely comprised the majority of the infrastructure being removed and the mine portals sealed.

5.3.1.1 TAILINGS IMPOUNDMENT

In 1981, the State Government made the decision to rehabilitate the Radium Hill tailings impoundment and to utilise the structures as a repository for low-level radioactive waste. Condition of the dams at this time (some 20 years after the cessation of mining) had deteriorated considerably. By 11 May 1981, construction of new covers had been completed over the impoundment using material sourced from four adjacent borrow pits (Plan 3). These pits (Fig. 34) essentially formed a moat (designed in part to limit access) and potential containment area should the structure of the impoundment fail.

EW&S (1981–82) reported that rehabilitation of the impoundment included the covering of the No. 1 and No. 2 tailings impoundment as follows:

- an earth embankment of 3.5 m minimum thickness was constructed around the circumference of the main tailings impoundment
- a compacted earth blanket of 1 m minimum thickness was placed over the top of the upper (No. 2) impoundment and finished to a dish shape to ensure that rainwater would be held on top to soak in or evaporate, rather than scour the embankments
- a 1 m thick earth blanket was constructed over the part of the lower (No. 1) impoundment in which the repository was being filled
- a 400 mm earth blanket was placed over the remainder of the lower (No. 1) impoundment, with a stockpile of earth above the front edge of the repository to aid in covering (at the time) for future placements
- approximately 73 000 m^3 of earth was excavated from the surrounding borrow pits and carted during the rehabilitation exercise.

Although recommended, the impoundment was not armoured during this period due to cost factors. The budgeted cost of rehabilitation of the tailings impoundment and construction of road works was estimated at $200 000, with an actual realised cost of $156 000; armouring was estimated at another $50 000 (Hill, 1986). See Figures 35 and 36 for photographs of completed cover, and section 3.4.4 for further details on rehabilitation of the tailings impoundment.

Fig. 34. *Excavating material from borrow pits, with the tailings impoundment directly behind, 1981. (Source PIRSA 049699)*

5.3.1.2 ONGOING MAINTENANCE.

The only regular maintenance undertaken by PIRSA is generally to organise for the main track to the site to be graded once a year. Other maintenance or remedial activities are undertaken on an 'as needed' basis, with examples provided in Table 12.

Table 12 *Radium Hill rehabilitation and cleanup activities.*

Date	Work undertaken	Reference
March 1998	Erosion channel in tailings impoundment repaired. Contouring of impoundment surface undertaken to divert further runoff. Backfilling undertaken near old main shaft to cover an area of slumping.	MO7033/02
April 1994	Repairs to roads and other areas.	MO7033/02
Nov 1993	Repairs and covering to tailings dump.	ENV 10325
Aug 1993	General cleanup of numerous areas including scrap steel, concrete etc. Subsiding shaft near Browns Shaft backfilled. Materials from AMDEL located in borrow pit areas surrounding the main tailings impoundment buried.	ENV 10325, SR5/6/129
Aug–Sept 1991	Repairs to old stope breakthroughs and shafts.	MO 7033/002
April 1985	Golden Stairway Shaft was infilled, and deep guttering on the main impoundment wall was infilled. Fence extended around area of subsidence above main workings.	SR5/6/129
March–April 1981	Major cleanup including rehabilitation of main tailings impoundment and establishment of waste repository. Other areas of tailings waste rock etc. moved or covered. Drill cores onsite were also buried, presumably into the main tailings impoundment during rehabilitation.	SR5/6/129

Fig. 35 *Three months after completion of the Radium Hill tailings impoundment cover, 1981 (Source PIRSA 049706)*

Fig. 36 *Panoramic view of tailings impoundment from the northeastern corner, 2002 (Source PIRSA 049697)*

5.4 CHAPTER SUMMARY

Site monitoring by officers of the PIRSA Regulation and Rehabilitation Branch is generally on an annual basis to inspect the existing condition of structures and containment areas. In addition, staff from PIRSA (e.g. the Geological Survey Branch) and others may occasionally visit the site for various purposes and, if and where required, notify the Regulation and Rehabilitation Branch of any issues that may need attention.

Although current assessments on the potential to re-mine the remaining uranium resources are not favourable, some potential may exist in the future to extract further uranium from underground, or rare earth elements from the tailings material. In addition, the continual pursuit of other minerals within the area may also lead to further mining development in the near vicinity of the former mine.

Other than the major rehabilitation effort of 1981 to cover the existing tailings impoundment, most of the subsequent maintenance rehabilitation has been related to the portals and near-surface areas of stoping of the underground mine workings. It is considered that due to observed movement in and around this area, further remedial work may be required on the former mine portals.

CHAPTER 6 — RISK MANAGEMENT

6.1 INTRODUCTION

Risk management can be seen as the process of systematically identifying hazards, assessing the likelihood and consequence of those hazards, and making informed judgements based on the evaluation of these results. This report largely targets the first component 'hazard identification', with subsequent reports considering the assessment and management of these hazards.

6.2 NON-RADIOLOGICAL HAZARDS

Whilst the major focus of this report is on the radiological aspects of the site, often the non-radiological hazards will be more evident and in some instances of greater concern. Table 13 lists each of the areas of the site, including the township, and considers various potential hazards that may be present

Table 13 *Considered non-radiological hazards at Radium Hill.*

Area description	Underground workings	Subsidence	Industrial and residential waste	Structures and machinery	Erosion and sedimentation	Piles and impoundments	Chemicals, explosives etc.	Dust	Visual amenity
Underground mine workings	✓	✓	✓	✓			✓		✓
Mine surface infrastructure area			✓	✓				✓	✓
Mill and treatment area			✓	✓			✓	✓	✓
Support buildings area			✓	✓			✓	✓	✓
Support infrastructure areas			✓		✓		✓		✓
Tailings dumps area					✓	✓		✓	✓
Waste rock dumps					✓	✓		✓	✓
Township			✓	✓					✓
Regional workings	✓	✓	✓		✓			✓	✓
Waste disposal areas			✓	✓	✓	✓	✓	✓	✓

6.3 RADIOLOGICAL HAZARDS

Radiological hazards associated with the mining and milling of uranium are determined by what happens to the daughter products during each of the phases of the operation. During processing, uranium is removed from the ore, but what remains is often no less hazardous than the ore from which it was extracted. This is largely because the tailings still contain 85% of the radioactivity (WISE Uranium Project 2004) and are now in a condition whereby they are more mobile due to the changed physical and chemical properties of the material. Potential hazards remaining from earlier mining and treatment of the ore for the Radium Hill site are discussed below.

6.3.1 RADON

When a deposit is mined, radon gas can escape into the air, ore dust can be blown by the wind, and contaminants can be leached and seep into surface water bodies and groundwater (WISE Uranium Project 2004). Similar events will also occur from mill tailings, noting that not all the radon produced in the tailings will be released to the environment. Some will decay before it can diffuse out of the tailings and some will be retained within. Upon closure of a mine as in the Radium Hill site, the tailings will dry out following the cessation of operations, and release of radon will increase to its maximum amount unless curbed in some way e.g. by covering. Any released radon will be quickly diluted in the atmosphere where it has been estimated under average meteorological conditions that a dilution of 200 to 300 will occur within a few hundred metres downwind of the tailings (Fry, as cited in Wilkinson, 1977).

6.3.2 EXTERNAL RADIATION

Generally, the removal of much of the high-grade ore will lower actual radiation levels from their source. This can change, however, where waste rock and rejects are placed on the surface or in areas where original radiation was low. As with tailings, the dose rate falls quickly with distance from the radioactive material and generally will be around background levels within 50 m from a source pile etc. Covers (i.e. currently over the tailings heaps) help to substantially reduce gamma exposure levels.

6.3.3 RADIOACTIVE DUST

Dust can be associated from mine waste ore, but is generally more applicable to that generated from the tailings prior to covering. As previously mentioned, upon cessation of mining operations the tailings would have dried out, and the material became susceptible to dispersal in the form of dust by wind movement. The results of this process are readily observed at the Radium Hill site where material can be noted over a large area generally in relation to the prevailing winds both from the tailings area and the areas of stockpiles and waste rock where it is believed these have been crushed for use as ballast and road material. In terms of the tailings impoundment, covering in 1981 has eliminated this dispersal process.

6.3.4 RADIOACTIVE SEEPAGE

During mining operations, seepage from the tailings area would have been limited by the tailings impoundment design, although no information has been located to verify what and if any has occurred because of wet placement. After the natural drying out of the tailings (and prior to the placement of covers), rain falling directly on the surface would have been the only source of seepage, and upon covering, only rainfall that which has percolated through the covers (Fry, as cited in Wilkinson, 1977).

6.4 CONTAMINANT ASSESSMENT

As with the assessment of non-radioactively contaminated sites, the concept of determining a linkage from a source via a pathway to a receptor can be utilised to understand fate and transport mechanisms of contaminants on the site.

'There can be a radiological impact from the contamination only if there is a source (radioactively contaminated land) and also one or more pathways and receptors.' (Environment Agency, 2002, p.22)

6.4.1 MODES OF POTENTIAL RELEASE

Contaminants may be released by a number of different processes from uranium mill tailings and associated process wastes. The following is provided by the International Atomic Energy Agency (2002):

- water and wind erosion
- geotechnical instabilities
- controlled release of contaminated water
- spills during the transport of tailings or mine waste
- unauthorised removal of tailings and mine waste
- construction of buildings on tailings and mine waste
- radon emission
- dust emission
- direct gamma radiation
- seepage
- diffusion processes.

6.4.2 SOURCES

6.4.2.1 INTRODUCTION

Radiation sources are either natural background or man made. Natural background sources include cosmic, terrestrial and internal radiation. Whilst all living things are exposed to these natural background radiation sources, two groups may be exposed to man-made radiation sources, namely members of the public and occupationally exposed individuals. These man-made sources may include:

- X-rays and nuclear medicine
- fuel cycle which includes the entire sequence from mining and milling of uranium to disposal of the used (spent) fuel
- televisions, smoke detectors, lantern mantles etc.
- Research etc.

6.4.2.2 RADIUM HILL

Other than naturally occurring background sources from the Radium Hill site, the main radioactive source relates to the remnants from the mining and milling (concentrating) process of ore extraction. This is predominantly made up of waste rock, mine tailings, and material located within the repository. These can occur in a number of different forms including gamma radiation, dust, leachate etc. when considering radioactive hazards.

6.4.3 EXPOSURE PATHWAYS

6.4.3.1 INTRODUCTION

When considering the impact on humans, each of the different routes or pathways that can expose people to radiation result in exposure to different parts of the body. Exposure pathways can be highly site specific, but for radiation exposure they can be generalised as follows:

1) atmospheric pathways that can give rise to doses due to inhalation of radon and its progeny, and airborne radioactive particles

2) atmospheric and terrestrial pathways that can give rise to doses resulting from external radiation and ingestion of contaminated soil and foodstuffs

3) aquatic pathways that can give rise to doses from ingestion of contaminated water, food produced using contaminated irrigation water, fish and other aquatic biota, and food derived from animals drinking contaminated water, and from external radiation (IAEA, 2002).

6.4.3.2 RADIUM HILL

Within arid areas such as Radium Hill, dust particles and radon gas are major contributors to the estimated radiation dose, via airborne dispersion and by inhalation (IAEA, 2002). In terms of human exposure (and in most instances applicable to fauna), a number of potential pathways have been considered; Table 14 lists these and provides an estimate of the likely potential of their occurrence in relation to the Radium Hill site. Figure 37 diagrammatically presents the various pathway scenarios.

Table 14 *Human radiation exposure pathways.*

Method	Pathway	Comment	Likelihood
Ingestion	Of soil and dust	Rarely visited	Possible
Ingestion	Of agricultural products and locally grown produce	The area is grazed by sheep largely for wool production; closest residences are approx 15 km away.	Unlikely
Ingestion	Of native flora	Few species	Unlikely
Ingestion	Of drinking water	Semi-arid area, with no permanent water bodies. Saline groundwater.	Unlikely
Ingestion	Of soil attached to edible flora	As above	Unlikely
Inhalation	Of dust	As above	Possible
Inhalation	Of radioactive gases	As above	Possible
External	External exposure	As above	Possible
External	Dermal contact	Requires direct contact	Possible

6.4.4 RECEPTORS

6.4.4.1 INTRODUCTION

The use of the term ‘receptor’ can be readily interchanged with ‘target’, with this report largely considering the potential impact on humans as the final target or receptor.

6.4.4.2 RADIUM HILL

Potential exposure receptors at Radium Hill that can be directly affected include:

- people
- water (surface and groundwater)
- flora (native and introduced)
- fauna (native and introduced)
- soil
- air

Other targets not readily considered may include non-direct impacts e.g. public opinion and effects on rehabilitation and revegetation attempts.

6.4.5 CONCEPTUAL MODEL

A conceptual model (Fig. 37) of the site helps to diagrammatically present the available information relating to the source(s) of contamination, the pathways along which these migrate, the transportation mechanism, and the receptor or target that may be affected. The model may be further tested and refined as more information comes to hand.

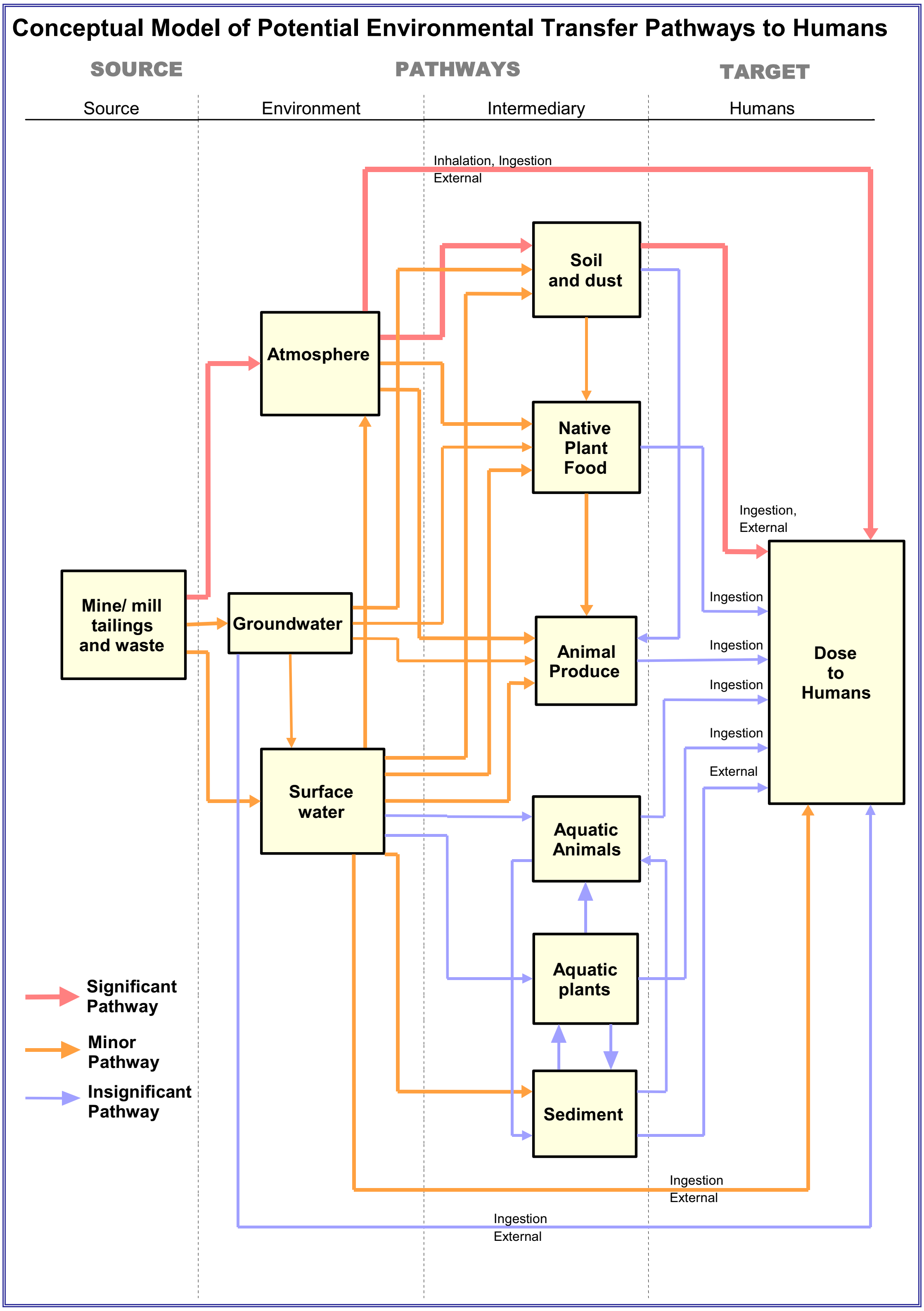


Fig. 37 Conceptual model of potential environmental transfer pathways to humans at Radium Hill (adapted from IAEA, 2002).

6.5 CURRENT AND FUTURE ACTIVITIES

Risk scenarios can be determined and developed by considering current and future activities on, and in close proximity to, the site, including both observed and potential.

6.5.1 CURRENT ACTIVITIES

6.5.1.1 STATION DUTIES

As the land is fully covered by grazing leases, it can be expected that in addition to sheep being present, associated tasks would be undertaken by employees of the local station. However, given the overall size of the station property, the actual time spent within the general mine area would be minimal.

6.5.1.2 PIRSA AND OTHER GOVERNMENT DEPARTMENTS

Staff from the PIRSA Regulation and Rehabilitation Branch access the site on an infrequent basis, generally by four-wheel-drive vehicle for inspection purposes, monitoring and sampling. The PIRSA Geological Survey Branch visits the general area during mapping and sampling exercises.

6.5.1.3 RADIUM HILL HISTORICAL ASSOCIATION

Annual gatherings are generally organised around Easter where 20–40 people attend, usually for a period of 3–4 days; 2004 marks the 50th anniversary since the mine officially opened in 1954.

6.5.1.4 OTHER

The site is an area of geological interest and thus generates visits from groups who study and/or explore (e.g. exploration companies) the area on an irregular basis. The area also attracts a number of people throughout the year who visit the site purely out of interest, social connection or in relation to the site's status as a former uranium mine.

6.5.2 POTENTIAL FUTURE ACTIVITY SCENARIOS

A number of scenarios for human exposure can be considered and, whether realised or not, help to provide a long-term assessment of potential risks related to the site. The following list is presented for discussion purposes only and is not intended to suggest that any of these activities will or may occur; the list is not intended to be fully conclusive of all potential scenarios.

- area is re-mined and/or material reprocessed
- massive or gross erosion
- increased interest in heritage aspects of the site, including archaeological interest in the long-term
- nomadic inhabitation
- effects following climatic change, including a change of land use

6.6 PRELIMINARY RISK ASSESSMENT

Due to the inevitability of risk assessments being misrepresented or taken out of context, the following information is provided in preliminary form only until more complete data and information are obtained in order to characterise the site and make better informed judgements on potential risks that may be associated with the site. In addition, only the radiological environment is considered at present; this does not preclude the potential importance of hazards that may be associated with the non-radiological environment in any way or form.

6.6.1 RADIOLOGICAL ENVIRONMENT

From current available data, annual dose rates and cumulative dose rates have been modelled on a number of potential (although in most cases unlikely) scenarios of an adult human being exposed to various radiation levels throughout the site (Table 15). These scenarios include an adult human visiting and/or residing (or remaining motionless) within these various areas for different periods.

> A limit not exceeding 1 milli sievert (mSv) as an annual effective dose to a member of the public has been set by a number of guidelines and regulations including the *Radiation Protection and Control (Ionising Radiation) Regulations 2000*.

Note: These scenarios are presented based on there being no form of shielding present e.g. within a vehicle, caravan or building, in addition to the person remaining the entire period within the same spot or location. Only direct gamma radiation is assessed and does not include other potential radioactive pathways as discussed in previous sections. The measurements also include natural background radiation levels.

Scenario 1. A brief visit by a member of the public, including spending time on or within individual areas around the site, e.g. PIRSA site inspection, visit by station personnel:

- 3 hours in one year
- 3 hours each year over 10 years.

Scenario 2. An overnight visit by a member of the public to the site including spending the entire time on or within individual areas around the site, e.g. overnight camper:

- 24 hours in one year
- 24 hours each year over 10 years.

Scenario 3. A week's residence by a member of the public, including spending the entire time on or within individual areas around the site, e.g. extended stay by a visitor and remaining within the same location:

- 168 hours (one week) in one year
- 168 hours (one week) each year over 10 years.

Scenario 4. An entire year of residence by a member of the public, including spending the entire time on or within individual areas around the site, e.g. highly unlikely scenario of a visitor remaining within one location for an entire year(s):

- 24 hours per day, 365 days per year
- 24 hours per day, 365 days per year over 10 years.

Table 15 *Preliminary gamma dose risk assessment scenarios for Radium Hill.*

Locality	Scenario	Occupancy period (hours)	Annual dose (mSv/y)*	Cumulative dose (mSv)* 10 years
Top of slimes dump	Sc 1.	3	0.0007	0.007
	Sc 2.	24	0.006	0.06
	Sc 3.	168	0.042	0.42
***Dose: 0.25 (µSv/hr)**	Sc 4.	8760	2.191	21.91
On gravel road	Sc 1.	3	0.0012	0.012
	Sc 2.	24	0.0096	0.096
***Dose: 0.4**	Sc 3.	168	0.0672	0.672
(µSv/hr)	Sc 4.	8760	3.506	35.06
Top of screens	Sc 1.	3	0.0045	0.045
	Sc 2.	24	0.036	0.36
***Dose: 1.5**	Sc 3.	168	0.252	2.52
(µSv/hr)	Sc 4.	8760	13.14	131.4

* This dose includes 'normal background' radiation (see Appendix 2 for further details related to estimated background measurements)

6.7 CHAPTER SUMMARY

Within arid areas such as at Radium Hill, dust particles, gamma radiation and radon gas are the main contributors to the potential radiation dose.

Whilst no definitive radiological studies have been undertaken in recent years, random sampling from the area indicates elevated (relative to background) gamma levels on areas of waste rock and mill tailings together with those areas where waste rock has been used during development and operation of the former mine.

Based on preliminary figures, people facing the greatest exposure (although considered to be minute) to elevated radiation levels based on current activities are those who spend extended periods of time at the site, namely overnight campers etc.

A 'conceptual model of potential environmental transfer pathways to humans' has been developed that helps to diagrammatically present the available information relating to the source(s) of contamination, the pathways along which it migrates, by what mechanism it is transported, and the receptor or target that may be affected.

CHAPTER 7 — RECOMMENDATIONS

7.1 AUDITS AND RECOMMENDATIONS

Over the years since decommissioning of the treatment site, inspections and audits have resulted in recommendations being made relating to various aspects of the site and its management. Conditions have also been placed on the site as part of the certificate of registration for the site under the RPC Act (Chapter 1).

7.1.1 AUDITS

In August 2002, the South Australian Government announced that the EPA would conduct an audit of radioactive material in South Australia. This was undertaken in 2003 and the report *Audit of Radioactive Material in South Australia* was published in September 2003. The audit applied only to radioactive material containing radionuclides with activity concentrations at levels regulated by the RPC Act, and included radioactive tailings and residues at Radium Hill and Port Pirie, where uranium ore was mined or processed in the past.

Resulting from this audit were a number of key recommendations including two relevant to the Radium Hill site:

- 'that future management of South Australia's radioactive waste be in accordance with internationally agreed principles'
- 'that regulatory control of sites containing radioactive waste be kept under review to provide an appropriate system for radioactive waste management for protection of human health and the environment.'

In addition, two general recommendations made specifically related to the site:

- 'that long-term management plans be developed as required by conditions of registration of the Radium Hill site under the *Radiation Protection and Control Act 1982*'
- 'that the government develop options for management of the types of waste previously disposed of at the Radium Hill repository.'

The audit inspection also found that the tailings dams were in 'fair condition with little degradation of the clay capping' and that there was 'no degradation of the cover on materials buried in the repository area'.

PIRSA's present management arrangements and the Radium Hill – Port Pirie site characterisation study (this report forming phase 1) ensure the implementation of these recommendations.

7.2 PHASE 2 CHARACTERISATION

Very little data are available at present to fully characterise the various attributes of the site, however the data that are available do warrant further investigation and interpretation. In order to progress to phase 2 of the management plan, the following recommendations are provided:

7.2.1 GENERAL

- Check validity of previous sampling studies (where possible).
- Develop and build a database to store current and future data in order to provide readily available access. Existing databases may be utilised or possibly amended.
- Determine baseline data including analysis for total U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{232}Th and ^{228}Ra in addition to undertaking a full metal scan. These samples should include tailings and waste rock.
- Re-photograph where possible a standard set of images based on original site photos in order to make comparisons of the current and future status of the area. Establish a number of permanent photo base points throughout the site.
- Assess currently available risk and radiological exposure models.
- Consider possible future land-use options and model potential future scenarios for near, medium and long-term timeframes. Variables such as consequences of climate change should be included.
- Define a boundary for the study site e.g. will only the area defined as the repository be included, thereby excluding the township and parts of the nearby exploration disturbances.
- Refine the conceptual model.

7.2.1.1 FURTHER INFORMATION SOURCES

It is recommended that attempts be made to locate and source the following information; these have either been requested and not received prior to completion of this report, are not readily locatable, or are currently in progress:

- Remaining original mine production tables.
- Mill production tables.
- Files relevant to Radium Hill and the low-level waste repository from AMDEL.
- Results of sampling undertaken by the EPA in January 2004.

During the course of the investigative stage, a number of personnel with extensive knowledge of the site have been identified. It is proposed as part of the phase 2 investigations to collate this information in order to clarify the existing understanding of the site and, where applicable, include further related information.

7.2.2 RADIOLOGICAL CHARACTERISATION

- A detailed radiometric survey (gamma) should be undertaken across the designated site and surrounding area. This survey should be directed to detailed coverage over the immediate mine site and tailings area, with all measurements being accurately georeferenced.
- Undertake radon assessment of surface material and air venting from underground workings.
- Determine airborne dust quality.

7.2.3 HYDROLOGICAL CHARACTERISATION

- Determine if and to what extent there is a presence of an 'environmental halo' surrounding the site by sampling the groundwater.
- Determine surface water and sediment quality.

7.2.4 GEOLOGICAL AND ENGINEERING CHARACTERISATION

- Accurately re-survey the cover over the tailings impoundment to quantify thickness, slopes and distribution of material in order to assess future maintenance issues and strategy.
- Complete a detailed inventory and characterisation of soil and rock material potentially suitable for remediation purposes.
- Determine stability and erosion potential of impoundments etc.
- Determine stability of underground workings; determine zones of weakness.
- Using a suitable GIS program, combine existing plan and level diagrams of the underground workings to form a three dimensional model. This will help determine those areas with a potential to collapse in addition to calculating void volumes and underground migration pathways.

7.3 MANAGEMENT, MAINTENANCE AND MONITORING

The following recommendations are based on site observations and generally accepted principles of 'best practice' site management:

- Determine investigation levels and establish objectives and goals for potential site remediation. Establish risk levels acceptable for protection of human and ecological health and safety.
- Develop a comprehensive communication plan. The investigation and potential rehabilitation by government of the Port Pirie site will rely heavily on the active input of the community at large to ensure the success of the subsequent phases relating to management of the site.

- Standardise site inspections to maximise time and effort required. This should include standard measurements and inspections of workings being undertaken on each visit.

- Develop a Health, Safety and Environment (HSE) plan for the site for current operations and for further possible site characterisation studies.

- Include the township and nearby workings related to either initial exploration and/or mining within the overall management of the site.

- Mark accurately on the ground (star dropper) all locations of former openings (known or suspected) to aid in monitoring of subsidence etc.

- Install signage at the main entrances with an acceptance of liability upon traversing the area.

- Determine current visitation rates to the site, and consider and model potential future scenarios for near, medium and long-term timeframes.

7.3.1 RECOMMENDATIONS FOR IMMEDIATE ACTION

- Replace faded and damaged signs; install additional signage.

- Fix fencing; consider upgrading to standards set out in AS 1725–2003.

- Accurately determine designated boundaries; some discrepancies exist between digital and hardcopy information.

7.4 CHAPTER SUMMARY

A number of recommendations relating to management of the site have been made in the past, but these have not always (and in some instances not considered necessary) been enacted.

The focus of the recommendations is towards preliminary investigative studies in order to characterise the site and progress to phase 2 of the management plan. Some immediate attention to detail is required, including determining actual study boundaries and verifying current cadastral boundary descriptions.

Since 1998, no further deposits of low-level radioactive waste have been made to the low-level radioactive waste repository and, together with further recommendations from the EPA that the site would not meet current engineering standards, it is considered unlikely that the repository will see the burial of more material.

***Table 16** Previous recommendations for the Radium Hill site.*

Source and date	Area	Recommendation	Action	Notes
SAICORP (1996) Radium Hill Risk Audit	Access	In view of the inherent exposure, it is recommended that MESA (PIRSA) not encourage public visitation to the site by not providing signposting to Radium Hill from the Barrier Highway or any other access road.	Current management strategy includes this.	
SAICORP (1996)		Assuming that MESA does not intend to increase casual public visitation to Radium Hill in a desire to limit its public liability exposures, it is recommended that MESA (PIRSA) does not promote Radium Hill in any tourism medium.	Current management strategy includes this.	
SAICORP (1996)		Visitation requests by members of the public should be considered by MESA (PIRSA) and, if approved, then that approval should be given conditionally, e.g. limited length of stay, no camping in specific areas etc.	Partially in place, no formal or documented approval process.	
SAICORP (1996)	Access — Radium Hill Reunion Committee	In consideration of the risk management work already undertaken throughout the Radium Hill site, and the strong interest of the former residents of the town in its history, SAICORP recommends that the Radium Hill Reunion Committee be permitted to access the site on a conditional basis.	Ongoing.	
SAICORP (1996)		It is recommended that the conditions imposed on any approval for the Radium Hill Reunion Committee visits include a prohibition on public advertising or promotion of Radium Hill, or of the tours to be undertaken of the site by committee members as former residents, in order not to attract new groups of visitors ignorant of the potential radiation hazards.	?	
SAICORP (1996)		MESA (PIRSA) should not permit the erection of plaques or other permanent structures by any person within the Radium Hill boundary.		Known to be occurring

SAICORP (1996)		Approval for burial within the Radium Hill cemetery by former town residents should be subject to all state burial regulations.		
SAICORP (1996)	Fencing	It is recommended that existing fencing be maintained whilst the ground it encircles remains unstable.	Current management strategy includes this.	
SAICORP (1996)		SAICORP sees no need to fence any other portion of the site.		The author does not support this recommendation. In view of unknown underground stoping etc., together with observed subsidence in areas outside the area of fencing, it is premature to agree with this, and warrants further investigation to determine zones of weakness.
SAICORP (1996)	Signage	The signs currently located around the site be retained and maintained, but that no additional signs be erected by MESA (PIRSA).	It is believed that signage noted here is the same as presently in place. However, many signs have now faded and are in need of replacement (2004).	The author supports most of this recommendation but is of the view that additional signage is warranted, in particular, initial warnings upon entering the site, together with an acceptance of liability by persons traversing past these same signs. Signage will become more important in following years when the potential increases for records to be lost or relevant site information to be forgotten.
SAICORP (1996)	Hazard management	That the repository not be identified or made obvious by way of erection of signs or fencing.	?	Unsure what is implied here as at the time (observable in photos) the repository is identified by signage. The author is also of the view that further signage is warranted on the repository site

R.J Jewell (1996)	Management	That a report be prepared, documenting the history, operations, construction and current state of the mine and, in particular, the tailings storage facility. This will consolidate the information and knowledge of the site into a form suitable and available for scrutiny should that be required in the future.	Will be covered by this report.	
EPA (2003)		That long-term management plans be developed as required by conditions of registration of the Radium Hill site under the RPC Act.	This report will complete phase 1 of this management plan.	
EPA (2003)		That the government develop options for management of the types of waste previously disposed of at the Radium Hill repository.		
R.J. Jewell (1996)	Tailings	It may be necessary to protect the slope with rock armouring, if protection against scour has to be ensured into the future.	Will be considered upon finalisation of phase 2.	

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APPENDICES

APPENDIX 1. ABBREVIATIONS

Units

Metric units are used throughout this report and in many instances will have been converted from imperial units in older reports, files and plans. Much of this report deals with levels of radioactivity in various media. International standards will be used as follows:

Absorbed dose	gray	(Gy)
Effective dose equivalent	sievert	(Sv)
Radiation activity	becquerel	(Bq)

Common Radiation Units - SI - International Standard

The following is sourced from the Idaho State University (ISU 2003) website: http://www.physics.isu.edu/radinf/terms.htm

Note: These are the common units used throughout the world in health physics.

GRAY (Gy)

The gray is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One gray is equal to one joule of energy deposited in one kg of a material. The unit gray can be used for any type of radiation, but it does not describe the biological effects of the different radiations. Absorbed dose is often expressed in terms of hundredths of a gray, or centi-grays. One gray is equivalent to 100 rads.

SIEVERT (Sv)

The sievert is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of millionths of a sievert, or micro-sievert. To determine equivalent dose (Sv), you multiply absorbed dose (Gy) by a quality factor (Q) that is unique to the type of incident radiation. One sievert is equivalent to 100 rem.

BECQUEREL (Bq)

The Becquerel is a unit used to measure a radioactivity. One Becquerel is that quantity of a radioactive material that will have one transformations in one second. Often radioactivity is expressed in larger units like: thousands (kBq), one millions (MBq) or even billions (GBq) of a Becquerel. As a result of having one Becquerel being equal to one transformation per second, there are 3.7×10^{10} Bq in one curie.

Other Units

Other units of measure found in this report include:

ha	hectare
kg	kilogram
kpa	kilopascal
lt	litre
m	metre
m^2	square metre
m^3	cubic metre
mS/cm	micro siemen per centimetre
ppm	parts per million
ppt	parts per thousand
psi	pounds square inch
t	tonne

Prefixes

Prefixes used throughout the report include:

G	giga	1 000 000 000	1×10^9
M	mega	1 000 000	1×10^6
k	kilo	1000	1×10^3
m	milli	0.001	1×10^{-3}
µ	micro	0.000001	1×10^{-6}
n	nano	0.000000001	1×10^{-9}

Acronyms

Acronyms commonly referred to include:

AAEC	Australian Atomic Energy Commission
ACG	Australian Centre for Geomechanics
AHD	Australian Height Datum
AMDEL	Australian Mineral Development Laboratories

ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
CIM	Chief Inspector of Mines
DEP	Department of Environment and Planning
DHS	Department of Human Services
DPC	Department of Premier & Cabinet
EC	Electrical conductivity
EMP	Environmental Management Plan
EPA	Environmental Protection Authority
GIS	Geographical Information Systems
IBRA	Interim Biogeographical Regionalisation for Australia
MESA	Mines and Energy South Australia (Now PIRSA)
NHMRC	National Health and Medical Research Council
PIRSA	Primary Industries and Resources (SA)
PPUTP	Port Pirie Uranium Treatment Plant
REC	Rare Earth Corporation
REE	Rare Earth Elements
RHHS	Radium Hill Historical Society
SA	South Australia
SAICORP	South Australian Government Captive Insurance Corporation
SG	Specific Gravity
SLA	Statistical Local Area
TDS	Total Dissolved Solids
US EPA	United States Environmental Protection Agency

Chemical Abbreviations

Symbol	Element	Symbol	Element	Symbol	Element
Ac	Actinium	K	Potassium	Tc	Technetium
Ag	Silver	Kr	Krypton	Te	Tellurium
Al	Aluminium	La	Lanthanum	Th	Thorium
Am	Americium	Li	Lithium	Ti	Titanium
Ar	Argon	Lr	Lawrencium	Tl	Thallium
As	Arsenic	Lu	Lutetium	Tm	Thulium
At	Astatine	Md	Mendelevium	U	Uranium
Au	Gold	Mg	Magnesium	Uub	Ununbium
B	Boron	Mn	Manganese	Uun	Ununnilium
Ba	Barium	Mo	Molybdenum	Uuu	Unununium
Be	Beryllium	Mt	Meitnerium	V	Vanadium
Bh	Bohrium	N	Nitrogen	W	Tungsten
Bi	Bismuth	Na	Sodium	Xe	Xenon
Bk	Berkelium	Ne	Neon	Y	Yttrium
Br	Bromine	Nb	Niobium	Yb	Ytterbium
C	Carbon	Nd	Neodymium	Zn	Zinc
Ca	Calcium	Ni	Nickel	Zr	Zirconium
Cd	Cadmium	No	Nobelium		
Ce	Cerium	Np	Neptunium		
Cf	Californium	O	Oxygen		
Cl	Chlorine	Os	Osmium		
Cm	Curium	P	Phosphorus		
Co	Cobalt	Pd	Palladium		
Cr	Chromium	Po	Polonium		
Cs	Caesium	Pb	Lead		
Cu	Copper	Pt	Platinum		
Db	Dubnium	Pr	Praseodymium		
Ds	Darmstadtium	Pm	Promethium		
Dy	Dysprosium	Pu	Plutonium		
Er	Erbium	Pa	Protactinium		
Es	Einsteinium	Ra	Radium		
Eu	Europium	Rb	Rubidium		
F	Fluorine	Re	Rhenium		
Fe	Iron	Rf	Rutherfordium		
Fm	Fermium	Rh	Rhodium		
Fr	Francium	Rn	Radon		
Ga	Gallium	Ru	Ruthenium		
Gd	Gadolinium	S	Sulphur		
Ge	Germanium	Sb	Antimony		
H	Hydrogen	Sc	Scandium		
He	Helium	Se	Selenium		
Hf	Hafnium	Sg	Seaborgium		
Hg	Mercury	Si	Silicon		
Ho	Holmium	Sm	Samarium		
Hs	Hassium	Sn	Tin		
I	Iodine	Sr	Strontium		
In	Indium	Ta	Tantalum		
Ir	Iridium	Tb	Terbium		

APPENDIX 2. RADIATION

The following information relating to radiation, has been extracted from the International Atomic Energy Agencies (IAEA) website (www.iaea.org), and the Australian Radiation Protection and Nuclear Safety Agencies (ARPANSA) website (www.arpansa.gov.au).

RADIATION IN EVERYDAY LIFE

(Source: IAEA)

Radioactivity is a part of our earth — it has existed all along. Naturally occurring radioactive materials are present in its crust, the floors and walls of our homes, schools, or offices and in the food we eat and drink. There are radioactive gases in the air we breathe. Our own bodies — muscles, bones, and tissue — contain naturally occurring radioactive elements.

Man has always been exposed to natural radiation arising from the earth as well as from outside the earth. The radiation we receive from outer space is called cosmic radiation or cosmic rays.

We also receive exposure from man-made radiation, such as X-rays, radiation used to diagnose diseases and for cancer therapy. Fallout from nuclear explosives testing, and small quantities of radioactive materials released to the environment from coal and nuclear power plants, are also sources of radiation exposure to man.

Radioactivity is the term used to describe disintegration of atoms. The number of protons in the nucleus can characterize the atom. Some natural elements are unstable. Therefore, their nuclei disintegrate or decay, thus releasing energy in the form of radiation. This physical phenomenon is called radioactivity and the radioactive atoms are called nuclei. The radioactive decay is expressed in units called Becquerel's. One Becquerel equals one disintegration per second.

The radionuclides decay at a characteristic rate that remains constant regardless of external influences, such as temperature or pressure. The time that it takes for half the radionuclides to disintegrate or decay is called half-life. This differs for each radioelement, ranging from fractions of a second to billions of years. For example, the half-life of Iodine 131 is eight days, but for Uranium 238, which is present in varying amounts all over the world, it is 4.5 billion years. Potassium 40, the main source of radioactivity in our bodies, has a half-life of 1.42 billion years.

TYPES OF RADIATION (SOURCE: IAEA)

The term 'radiation' is very broad, and includes such things as light and radio waves. In our context it refers to "ionising" radiation, which means that because such radiation passes through matter, it can cause it to become electrically charged or ionised. In living tissues, the electrical ions produced by radiation can affect normal biological processes.

There are various types of radiation, each having different characteristics. The common ionising radiations generally talked about are:

- ***Alpha radiation*** consists of heavy, positively charged particles emitted by atoms of elements such as uranium and radium. Alpha radiation can be stopped completely by a sheet of paper or by the thin surface layer of our skin (epidermis). However, if alpha-emitting materials are taken into the body by breathing, eating, or drinking, they can expose internal tissues directly and may, therefore, cause biological damage.

- ***Beta radiation*** consists of electrons. They are more penetrating than alpha particles and can pass through 1-2 centimetres of water. In general, a sheet of aluminium a few millimetres thick will stop beta radiation.

- ***Gamma rays*** are electromagnetic radiation similar to X-rays, light, and radio waves. Gamma rays, depending on their energy, can pass right through the human body, but can be stopped by thick walls of concrete or lead.

- ***Neutrons*** are uncharged particles and do not produce ionisation directly. But, their interaction with the atoms of matter can give rise to alpha, beta, gamma, or X-rays which then produce ionisation. Neutrons are penetrating and can be stopped only by thick masses of concrete, water or paraffin.

Although we cannot see or feel the presence of radiation, it can be detected and measured in the minutest quantities with quite simple radiation measuring instruments.

RADIATION DOSE (SOURCE IAEA)

Sunlight feels warm because our body absorbs the infrared rays it contains. But, infrared rays do not produce ionisation in body tissue. In contrast, ionising radiation can impair the normal functioning of the cells or even kill them. The amount of energy necessary to cause significant biological effects through ionisation is so small that our bodies cannot feel this energy as in the case of infrared rays, which produce heat.

The biological effects of ionising radiation vary with the type and energy. A measure of the risk of biological harm is the dose of radiation that the tissues receive. The unit of absorbed radiation dose is the sievert (Sv). Since one sievert is a large quantity, radiation doses normally encountered are expressed in millisievert (mSv) or microsievert (μSv) which are one-thousandth or one millionth of a sievert. For example, one chest X-ray will give about 0.2 mSv of radiation dose.

On average, our radiation exposure due to all natural sources amounts to about 2.4 mSv a year--though this figure can vary, depending on the geographical location by several hundred percent. In homes and buildings, there are radioactive elements in the air. These radioactive elements are radon (Radon 222), thoron (Radon 220) and by products formed by the decay of radium (Radium 226) and thorium present in many sorts of rocks, other building materials and in the soil. By far the largest source of natural radiation exposure comes from varying amounts of uranium and thorium in the soil around the world.

The radiation exposure due to cosmic rays is very dependent on altitude, and slightly on latitude: people who travel by air, thereby, increase their exposure to radiation.

We are exposed to ionising radiation from natural sources in two ways:

- We are surrounded by naturally-occurring radioactive elements in the soil and stones, and are bathed with cosmic rays entering the earth's atmosphere from outer space.

- We receive internal exposure from radioactive elements which we take into our bodies through food and water, and through the air we breathe. In addition, we have radioactive elements (Potassium 40, Carbon 14, Radium 226) in our blood or bones.

Additionally, we are exposed to varying amounts of radiation from sources such as dental and other medical X-rays, industrial uses of nuclear techniques and other consumer products such as luminised wrist watches, ionisation smoke detectors, etc. We are also exposed to radiation from radioactive elements contained in fallout from nuclear explosives testing, and routine normal discharges from nuclear and coal power stations.

Mans exposure to ionising radiation (Source: ARPANSA)

Source Of Exposure	Exposure
Natural Radiation (Terrestrial and Airborne)	1.2 mSv per year
Natural Radiation (Cosmic radiation at sea level)	0.3 mSv per year
Total Natural Radiation	**1.5 mSv per year**
Seven Hour Aeroplane Flight	0.05 mSv
Chest X-Ray	0.04 mSv
Nuclear Fallout (From atmospheric tests in 50's & 60's)	0.02 mSv per Year
Chernobyl (People living in Control Zones near Chernobyl)	10 mSv per year
Cosmic Radiation Exposure of Domestic Airline Pilot	2 mSv per year

RADIATION PROTECTION (SOURCE IAEA)

It has long been recognised that large doses of ionising radiation can damage human tissues. Over the years, as more was learned, scientists became increasingly concerned about the potentially damaging effects of exposure to large doses of radiation. The need to regulate exposure to radiation prompted the formation of a number of expert bodies to consider what is needed to be done. In 1928, an independent non-governmental body of experts in the field, the International X-ray and Radium Protection Committee was established. It later was renamed the International Commission on Radiological Protection (ICRP). Its purpose is to establish basic principles for, and issue recommendations on, radiation protection.

These principles and recommendations form the basis for national regulations governing the exposure of radiation workers and members of the public. They also have been incorporated by the International Atomic Energy Agency (IAEA) into its Basic Safety Standards for Radiation Protection published jointly with the World Health Organization (WHO), International Labour Organization (ILO), and the OECD Nuclear Energy Agency (NEA). These standards are used worldwide to ensure safety and radiation protection of radiation workers and the general public.

An intergovernmental body was formed in 1955 by the General Assembly of the United Nations as the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). UNSCEAR is directed to assemble, study and disseminate information on observed levels of ionising radiation and radioactivity (natural and man-made) in the environment, and on the effects of such radiation on man and the environment.

Basic approaches to radiation protection are consistent all over the world. The ICRP recommends that any exposure above the natural background radiation should be kept as low as reasonably achievable, but below the individual dose limits. The individual dose limit for radiation workers averaged over 5 years is 100 mSv, and for members of the general public, is 1 mSv per year. These dose limits have been established based on a prudent approach by assuming that there is no threshold dose below which there would be no effect. It means that any additional dose will cause a proportional increase in the chance of a health effect. This relationship has not yet been established in the low dose range where the dose limits have been set.

There are many high natural background radiation areas around the world where the annual radiation dose received by members of the general public is several times higher than the ICRP dose limit for radiation workers. The numbers of people exposed are too small to expect to detect any increases in health effects epidemiologically. Still the fact that there is no evidence so far of any increase does not mean the risk is being totally disregarded.

The ICRP and the IAEA recommend the individual dose must be kept as low as reasonably achievable, and consideration must be given to the presence of other sources, which may cause simultaneous radiation exposure to the same group of the public. Also, allowance for future sources or practices must be kept in mind so that the total dose received by an individual member of the public does not exceed the dose limit.

In general, the average annual dose received by radiation workers is found to be considerably lower than the individual dose limits. Good radiation protection practice can thus result in low radiation exposure to workers.

IONISING RADIATION EXPOSURE TO THE PUBLIC

The following is sourced from the U.S Nuclear Regulatory Commissions website: http://www.nrc.gov

This chart shows that of the total dose of about 3600 μSv /year, natural sources of radiation account for about 81% of all public exposure, while man-made sources account for the remaining 19%. Natural and artificial radiations are not different in any kind or effect.

AT WHAT LEVEL IS RADIATION HARMFUL? (SOURCE: IAEA)

The International Commission on Radiological Protection (ICRP) has set the following limits on exposure to ionising radiation:

- The general public shall not be exposed to more than 1 mSv per annum (over and above natural background).
- Occupational exposure shall not exceed 20 mSv per annum

These limits exclude exposure due to background and medical radiation.

The effects of radiation at high doses and dose rates are reasonably well documented. A very large dose delivered to the whole body over a short time will result in the death of the exposed person within days. Much has been learned by studying the health records of the survivors of the bombing of Hiroshima and Nagasaki. We know from these that some of the health effects of exposure to radiation do not appear unless a certain quite large dose is absorbed. However, many other effects, especially cancers are readily detectable and occur more often in those with moderate doses. At lower doses and dose rates, there is a degree of recovery in cells and in tissues.

However, at low doses of radiation, there is still considerable uncertainty about the overall effects. It is presumed that exposure to radiation, even at the levels of natural background, may involve some additional risk of cancer. However, this has yet to be established. To determine precisely the risk at low doses by epidemiology would mean observing millions of people at higher and lower dose levels. Such an analysis would be complicated by the absence of a control group, which had not been exposed to any radiation. In addition, there are thousands of substances in our everyday life besides radiation that can also cause cancer, including tobacco smoke, ultraviolet light, asbestos, some chemical dyes, fungal toxins in food, viruses, and even heat. Only in exceptional cases is it possible to identify conclusively the cause of a particular cancer.

There is also experimental evidence from animal studies that exposure to radiation can cause genetic effects. However, the studies of the survivors of Hiroshima and Nagasaki give no indication of this for humans. Again, if there were any hereditary effects of exposure to low-level radiation, they could be detected only by careful analysis of a large volume of statistical data. Moreover, they would have to be distinguished from those of a number of other agents which might also cause genetic disorders, but whose effect may not be recognised until the damage has been done (thalidomide, once prescribed for pregnant women as a tranquilliser, is one example). It is likely that the resolution of the scientific debate will not come via epidemiology but from an understanding of the mechanisms through molecular biology.

With all the knowledge so far collected on effects of radiation, there is still no definite conclusion as to whether exposure due to natural background carries a health risk, even though it has been demonstrated for exposure at a level a few times higher.

RISKS AND BENEFITS (SOURCE: IAEA)

We all face risks in everyday life. It is impossible to eliminate them all, but it is possible to reduce them. The use of coal, oil, and nuclear energy for electricity production, for example, is associated with some sort of risk to health, however small. In general, society accepts the associated risk in order to derive the relevant benefits. Any individual exposed to carcinogenic pollutants will carry some risk of getting cancer. Strenuous attempts are made in the nuclear industry to reduce such risks to as low as reasonably achievable.

Radiation protection sets examples for other safety disciplines in two unique respects:

- First, there is the assumption that any increased level of radiation above natural background will carry some risk of harm to health.
- Second, it aims to protect future generations from activities conducted today.

The use of radiation and nuclear techniques in medicine, industry, agriculture, energy and other scientific and technological fields has brought tremendous benefits to society. The benefits in medicine for diagnosis and treatment in terms of human lives saved are enormous. Radiation is a key tool in the treatment of certain kinds of cancer. Three out of every four patients hospitalised in the industrial countries benefit from some form of nuclear medicine. The beneficial impacts in other fields are similar.

No human activity or practice is totally devoid of associated risks. Radiation should be viewed from the perspective that the benefit from it to mankind is less harmful than from many other agents.

Health effects arising from low doses of ionising radiation (Source: ARPANSA)

Effect	Risk	Normal Incidence
Risk of cancer from 1 mSv of radiation	1 in 17 000*	57 in 17 000**
Risk of severe hereditary effect from 1 mSv of radiation	1 in 77 000	1770 in 77 000

* Age standardised lifetime probability for whole population.
**Age standardised incidence rate for whole population (not necessarily fatal).

The risk of obtaining cancer from 1 mSv of radiation exposure is equivalent to the risk of getting cancer from smoking approximately 100 cigarettes.

APPENDIX 3. URANIUM RADIATION PROPERTIES

The following is derived from the 'World Information Service on Energy (WISE) — Uranium Project' relating to uranium ore and mill tailings.

URANIUM MILL TAILINGS

Uranium mill tailings are the residual waste from the process of uranium extraction from the uranium ore. Since only uranium is extracted, all other members of the uranium decay chains remain in the tailings at their original activities. In addition, small residual amounts of uranium are left in the tailings, depending on the efficiency of the extraction process used.

Within a few months, the isotopes of Th-234 and Pa-234m decay to the value given by the residual activity of the U-238. The total activity in the tailings then remains constant for more than 10 000 years at about 85% of that in the ore. Only after several hundred thousand years, when the Th-230 has decayed to the level of the residual U-234, a major decrease of total activity takes place. After this time, the activity of all members of the U-238 chain is equal to that of the residual U-238 and U-234, and it remains at this level for some billion years.

Compared to uranium ore, the alpha radiation of uranium mill tailings and thus the radiation hazard on ingestion or inhalation of tailings (dust) is approx. 25% lower, while the hazard from radon is unchanged. The external radiation hazard from gamma radiation remains nearly unchanged, while that from beta radiation is reduced. The chemical toxicity of uranium plays a minor role only in tailings.

URANIUM ORE

The following is derived from the 'World Information Service on Energy (WISE) – Uranium Project' relating to uranium ore and mill tailings.

In a uranium ore deposit, secular equilibrium obtains (sic) between U-238 and its decay products, and between U-235 and its decay products. The equilibrium may be somewhat disturbed by geochemical migration processes in the ore deposit. An ore grade of 1% U_3O_8 is equivalent to 0.848% U, and 1 million lbs U_3O_8 are equivalent to 385 metric tonnes of U.

The radiation is virtually trapped underground; exposures are only possible if contaminated groundwater that is circulating through the deposit is used for drinking. Radon is of no concern for deep deposits, though it can travel through underground fissures, since it decays before it can reach the surface.

The situation changes completely, when the deposit is mined: Radon gas can escape into the air, ore dust can be blown by the wind, and contaminants can be leached and seep into surface water bodies and groundwater.

The alpha radiation of the eight alpha emitting nuclides contained in the U-238 series (and to a lesser degree, of the seven alpha emitters in the U-235 series) presents a radiation hazard on ingestion or inhalation of uranium ore (dust) and radon. The gamma radiation mainly of Pb-214 and Bi-214, together with the beta radiation of Th-234, Pa-234m, Pb-214, Bi-214, and Bi-210, presents an external radiation hazard. For ingestion and inhalation, also the chemical toxicity of uranium has to be taken into account.

APPENDIX 4. EXAMPLE INSPECTIONS POST-1998

Note: Only includes inspections undertaken (or organised) by PIRSA or former Health Commission personnel from 1998 (Year of last deposit within the low-level radioactive waste repository.

Date	Attended by:	Comments
22/01/2004	M. McLeary (PIRSA), R. Cox (PIRSA), A. Johnston (EPA), T. Reif (EPA), C. Jeffries (EPA)	General inspection of areas, readings and soil samples taken from near tailings impoundment.
29/10/2003	P. Talbot (PIRSA), R. Cox (PIRSA)	Install corner marker posts for Radium Hill Reserve, check integrity of the sealed shafts within the site, and check integrity of the low level waste repository.
06/11/2002	G. Marshall (PIRSA), R. Cox (PIRSA), G. Palmer (EPA)	General observations recorded, inspection of rehabilitation on former workings.
02/07/2002	S. Caplygin (PIRSA), P.Talbot (PIRSA) and S. Silvester (PIRSA)	General inspection of shafts
12/06/2002	P. Talbot (PIRSA)	Inspection of collapse around shafts following email from A. Crooks
29/03/2001	S. Caplygin (PIRSA), P. Talbot (PIRSA)	Field notes related to workings and surface structure sites
10/11/1998	J. Boyce (PIRSA)	Report on site visit, includes draft PIRSA Radioactive materials holdings audit. Gamma readings from various areas of site
26/06/1998	D. Carbine (PIRSA)	Site inspection of repairs to Radium Hill tailings dam
23/04/1998	P. Talbot (PIRSA)	Noted: water movements had undercut concrete shaft slab. Photos included

APPENDIX 5. REPOSITORY DETAILS

The low-level radioactive waste repository is located within the top of the Radium Hill slimes dams as per the shaded area of Figure A5.1.

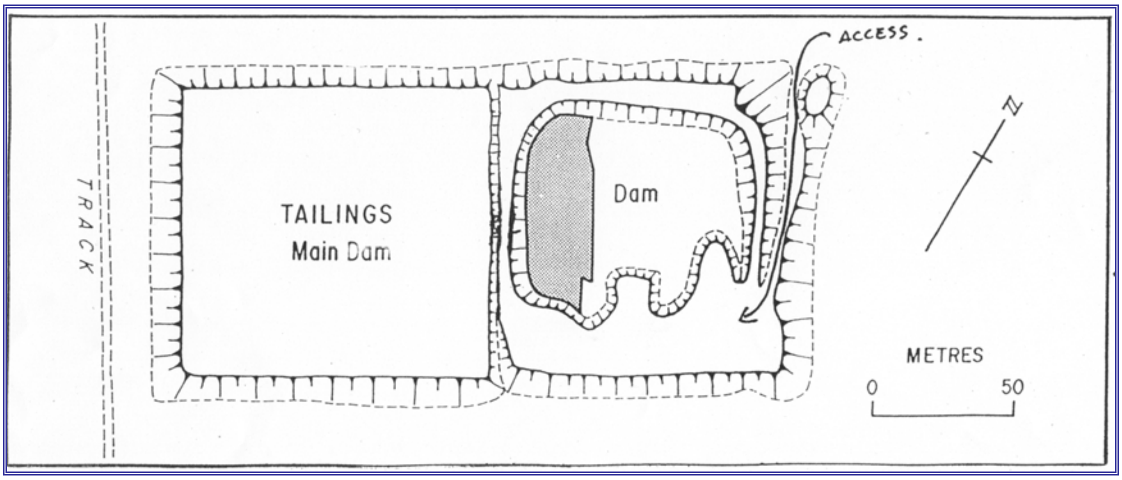
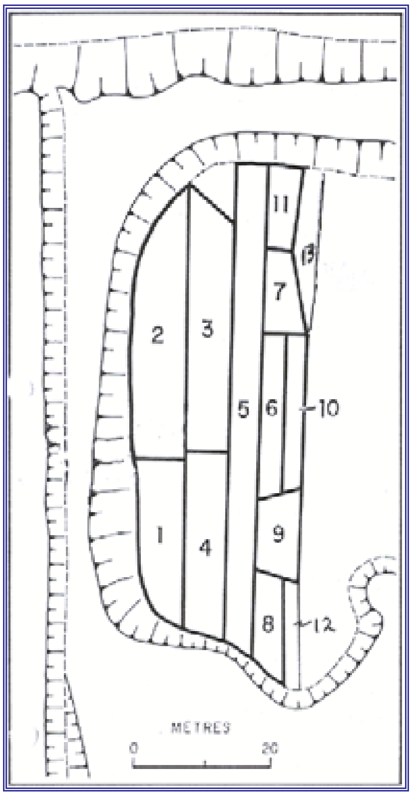


Figure A5.1. Location of low-level waste repository within tailings dam (slimes) radium Hill (Source PIRSA)

LOCATION AND CONTENTS OF BURIED MATERIAL

The following pages detail the various consignments of known wastes either buried within the repository itself (Figure A5.2) or in some instances (particularly low level soil material) buried within the mine workings and surrounding areas of the site.



AREA	Date of Deposit
1	February 1981
2	March 1981
3	March 1981
4	March 1981
5	March 1981
6	June 1982
7	September 1982
8	April 1983
9	April 1983
10	April 1985
11	August 1985
12	September 1986
13	July 1998

Figure A5.2. Location of buried waste within repository (Source PIRSA)

CONSIGNMENT 1

DATE

Date of Dispatch: 19/02/1981
Date of Deposit: 20/02/1981
Date of Burial: 21/02/1981

MATERIAL

Container Type: 200 L drum
Container Construction: Steel
Number of Units: 140
Media: Tailings/ Misc
Media Type Desc1: Lake way tailings/Assorted Chemical Assay Balances
Media Type Desc2: Leached tailing from 1978 program/ mixed uranium ore
Volume (L): 28 000
Weight: –

SOURCE, TRANSPORT AND LOCATION

Transferred from: AMDEL Thebarton
Consignee: AMDEL
Located into: Repository
Repository area: 1
Transport dockets: No
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: 7033.002.003
File 2: SR 5/6/129 vol.3
File 3: Envelope 4233
Confirmation of records: Yes
Photographic evidence: Yes
Diagram correlation: 160 x 200 L recorded total for date
Reference 1: Letter dated 4 May 1981 by AMDEL Manager: File 05/06/00129 volume 1, supports quantity
Reference 2: –
Comments: Expect volumes correct and media type 2 description.

CONSIGNMENT 2

DATE

Date of Dispatch: 09/03/1981
Date of Deposit: 10/03/1981
Date of Burial: 10/03/1981

MATERIAL

Container Type: 200 L drum/ 20 L drum
Container Construction: Steel
Number of Units: 210
Media: Tailings/Misc
Media Type Desc1: Lake way ore/Assorted Chemical Assay Balances/Dravo Ore
Media Type Desc2: Uranium ore from 1978 test program (Lake way)/Mixed uranium ore/Uranium ore from late 1980 test program (Dravo)
Volume (L): 26 340
Weight: –

SOURCE, TRANSPORT AND LOCATION

Transferred from: AMDEL Thebarton
Consignee: AMDEL
Located into: Repository
Repository area: 2
Transport dockets: No
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: SR 5/6/129
File 2: Envelope 4233
File 3: –
Confirmation of records: Yes
Photographic evidence: Yes
Diagram correlation: 160 x 200 L recorded total for date
Reference 1: Letter dated 4 May 1981 by AMDEL Manager: File 05/06/00129 volume 1, supports quantity
Comments: Expect volumes correct and media type 2 description.

CONSIGNMENT 3

DATE

Date of Dispatch:	**–**
Date of Deposit:	**17/03/1981**
Date of Burial:	**17/03/1981**

MATERIAL

Container Type:	**200 L drum**
Container Construction:	**Steel**
Number of Units:	**152**
Media:	**Ore?**
Media Type Desc1:	**Esso**
Media Type Desc2:	**–**
Volume (lt):	**30400**
Weight:	**–**

SOURCE, TRANSPORT AND LOCATION

Transferred from:	**–**
Consignee:	**Esso**
Located into:	**Repository**
Repository area:	**3**
Transport dockets:	**–**
Cartage Contractor	**–**

REFERENCE AND VERIFICATION

File 1:	**Envelope 4233**
File 2:	**–**
File 3:	**–**
Confirmation of records:	**No**
Photographic evidence:	**Yes**
Diagram correlation:	**80 x 200 L recorded total for date**
Reference 1:	**–**
Comments:	**–**

CONSIGNMENT 4

DATE

Date of Dispatch: 18/03/1981
Date of Deposit: –
Date of Burial: –

MATERIAL

Container Type: 200 L drum
Container Construction: –
Number of Units: 80
Media: Tailings
Media Type Desc1: AMC Tailings
Media Type Desc2: Leached tailing from early 1981 test program
Volume (L): 16 000
Weight: –

SOURCE, TRANSPORT AND LOCATION

Transferred from: AMDEL Thebarton
Consignee: AMDEL
Located into: Repository
Repository area: 3
Transport dockets: –
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: SR 5/6/129
File 2: –
File 3: –
Confirmation of records: No
Photographic evidence: –
Diagram correlation: As recorded
Reference 1: Letter dated 4 May 1981 by AMDEL Manager: File 05/06/00129 volume 1
Comments: Expect volumes correct and media type 2

CONSIGNMENT 5

DATE

Date of Dispatch: ?
Date of Deposit: 24/03/1981
Date of Burial: 24/03/1981

MATERIAL

Container Type: 200 L drum
Container Construction: –
Number of Units: 76
Media: Ore?
Media Type Desc1: Esso
Media Type Desc2: Leached tailing from early 1981 test program
Volume (L): 15 200
Weight: –

SOURCE, TRANSPORT AND LOCATION

Transferred from: –
Consignee: ESSO
Located into: Repository
Repository area: 4
Transport dockets: –
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: Envelope 4233
File 2: –
File 3: –
Confirmation of records: No
Photographic evidence: Yes
Diagram correlation: 160 x 200 L recorded total for date
Reference 1: –
Comments: –

CONSIGNMENT 6

DATE

Date of Dispatch: 23/03/1981
Date of Deposit: 24/03/1981
Date of Burial: 24/03/1981

MATERIAL

Container Type: 200 L drum/ 20 L drum
Container Construction: Steel
Number of Units: 228
Media: Tailings/ Ore/ Misc
Media Type Desc1: AMC Tailings/ Minatome/ AMC Ore/ Assorted chemical assay balances/ Lake way ore/ Gilfillan ore/ Esso ore/ Queensland Mines ore
Media Type Desc2: Leached ore tailing from early 1981 test program (AMC)/ Misc ore samples
Volume (L): 31 380
Weight: –

SOURCE, TRANSPORT AND LOCATION

Transferred from: AMDEL Thebarton
Consignee: AMDEL
Located into: Repository
Repository area: 5
Transport dockets: –
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: SR 5/6/129
File 2: –
File 3: –
Confirmation of records: No
Photographic evidence: Yes
Diagram correlation: 160 x 200 L recorded total for date
Reference 1: Letter dated 4 May 1981 by AMDEL Manager: File 05/06/00129 volume 1
Comments: –

CONSIGNMENT 7

DATE

Date of Dispatch:	**07/06/1982**
Date of Deposit:	**–**
Date of Burial:	**–**

MATERIAL

Container Type:	**200 L drum/ 20 L drum**
Container Construction:	**–**
Number of Units:	**184**
Media:	**Mix**
Media Type Desc1:	**Mainly soil**
Media Type Desc2:	**–**
Volume (L):	**13 760**
Weight:	**–**

SOURCE, TRANSPORT AND LOCATION

Transferred from:	**AMDEL Thebarton**
Consignee:	**AMDEL**
Located into:	**Repository**
Repository area:	**6**
Transport dockets:	**–**
Cartage Contractor	**–**

REFERENCE AND VERIFICATION

File 1:	**SR 5/6/129**
File 2:	**–**
File 3:	**–**
Confirmation of records:	**No**
Photographic evidence:	**–**
Diagram correlation:	**As recorded**
Reference 1:	**List from AMDEL Manager**
Comments:	**Mainly soil dug from surface around pughole. Assorted assay balances**

CONSIGNMENT 8

DATE

Date of Dispatch: 07/09/1982
Date of Deposit: 08/09/1982
Date of Burial: 08/09/1982

MATERIAL

Container Type: 200 L drum
Container Construction: –
Number of Units: 23
Media: Ore/?
Media Type Desc1: AMC Ore/ Core?
Media Type Desc2: –
Volume (L): 4600
Weight: –

SOURCE, TRANSPORT AND LOCATION

Transferred from: AMDEL Thebarton/ DME?
Consignee: AMDEL/ DME?
Located into: Repository
Repository area: 7
Transport dockets: –
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: SR 5/6/129
File 2: –
File 3: –
Confirmation of records: No
Photographic evidence: –
Diagram correlation: 80 x 200 L recorded
Reference 1: List from AMDEL Manager for AMDEL material
Comments: DME items from memo in file no other info found

CONSIGNMENT 9

DATE

Date of Dispatch:	**20/04/1983**
Date of Deposit:	**–**
Date of Burial:	**–**

MATERIAL

Container Type:	**200 L drum/ 20 L drum**
Container Construction:	**–**
Number of Units:	**132**
Media:	**Ore/ Mix/ Misc**
Media Type Desc1:	**Mainly soil/ AMC Ore/ Assorted chemical assay balances**
Media Type Desc2:	**–**
Volume (L):	**12 000**
Weight:	**–**

SOURCE, TRANSPORT AND LOCATION

Transferred from:	**AMDEL Thebarton**
Consignee:	**AMDEL**
Located into:	**Repository**
Repository area:	**8**
Transport dockets:	**–**
Cartage Contractor	**–**

REFERENCE AND VERIFICATION

File 1:	**SR 5/6/129**
File 2:	**–**
File 3:	**–**
Confirmation of records:	**No**
Photographic evidence:	**–**
Diagram correlation:	**58 x 200 L and 91 x 20 L recorded**
Reference 1:	**List from Peter AMDEL Manager**
Comments:	**Mainly soil dug from surface around pughole. AMC ore, assorted assay balances**

CONSIGNMENT 10

DATE

Date of Dispatch: 21/04/1983
Date of Deposit: 21/04/1983
Date of Burial: 21/04/1983

MATERIAL

Container Type: 200 L drum/ 50 L drum/ Misc
Container Construction: steel/ plastic/ loose
Number of Units: 10 drums
Media: Misc
Media Type Desc1: Cuneo filters/ Swimming Pool plastic liner/ 1.5-inch plastic hose/ Assorted plastic fittings
Media Type Desc2: –
Volume (L): 1250 + misc
Weight: –

SOURCE, TRANSPORT AND LOCATION

Transferred from: Honeymoon Project
Consignee: Administration Pty Ltd/ Southern Cross
Located into: Repository
Repository area: 9
Transport dockets: –
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: 7033.002.003
File 2: Loose file Radium Hill MO 7033 2
File 3: SR 5/6/129
Confirmation of records: Yes
Photographic evidence: –
Diagram correlation: As recorded
Reference 1: –
Comments: –

CONSIGNMENT 11

DATE

Date of Dispatch:	**15/04/1985**
Date of Deposit:	**17/04/1985**
Date of Burial:	**17/04/1985**

MATERIAL

Container Type:	**200 L drum**
Container Construction:	**–**
Number of Units:	**80**
Media:	**Ore/ Soil/ Misc**
Media Type Desc1:	**AMC Ore/ Assorted chemical assay balances/ Contaminated Soil/ Used plastic hose, containers etc**
Media Type Desc2:	**–**
Volume (L):	**16000**
Weight:	**–**

SOURCE, TRANSPORT AND LOCATION

Transferred from:	**AMDEL Thebarton**
Consignee:	**AMDEL**
Located into:	**Repository**
Repository area:	**10**
Transport dockets:	**–**
Cartage Contractor	**–**

REFERENCE AND VERIFICATION

File 1:	**7033.002.003**
File 2:	**SR 5/6/129**
File 3:	**–**
Confirmation of records:	**No**
Photographic evidence:	**Yes**
Diagram correlation:	**As recorded**
Reference 1:	**List from AMDEL Manager**
Comments:	**–**

CONSIGNMENT 12

DATE

Date of Dispatch: 28/08/1985
Date of Deposit: 29/08/1985
Date of Burial: 29/08/1985

MATERIAL

Container Type: 200 L drum/ 20 L drum
Container Construction: –
Number of Units: 41
Media: Ore/ Misc
Media Type Desc1: Ranger Ore/ Washing from concrete mixer/ Empty Contaminated Drums/ Plastic Sheet
Media Type Desc2: –
Volume (L): 6580
Weight: –

SOURCE, TRANSPORT AND LOCATION

Transferred from: AMDEL Thebarton
Consignee: AMDEL
Located into: Repository
Repository area: 11
Transport dockets: –
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: SR 5/6/129
File 2: –
File 3: –
Confirmation of records: No
Photographic evidence: Yes
Diagram correlation: As recorded except for 20 L containers
Reference 1: List from AMDEL Manager
Comments: –

CONSIGNMENT 13

DATE

Date of Dispatch: 01/09/1986
Date of Deposit: 01/09/1986
Date of Burial: 01/09/1986

MATERIAL

Container Type: 200 L drum
Container Construction: –
Number of Units: 16
Media: Soil/ Misc
Media Type Desc1: Contaminated soil dug from surface around pughole/ assorted chemical assay balances/ Concrete cores from calibration pits
Media Type Desc2: –
Volume (L): 3200
Weight: –

SOURCE, TRANSPORT AND LOCATION

Transferred from: AMDEL Thebarton
Consignee: AMDEL
Located into: Repository
Repository area: 12
Transport dockets: –
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: SR 5/6/129
File 2: –
File 3: –
Confirmation of records: No
Photographic evidence: Yes
Diagram correlation: As recorded
Reference 1: List from AMDEL Manager
Comments: –

CONSIGNMENT 14

DATE

Date of Dispatch: –
Date of Deposit: 09/09/1991 – 23/09/1991
Date of Burial: –

MATERIAL

Container Type: loose
Container Construction: –
Number of Units: –
Media: Soil
Media Type Desc1: Low level contaminated soil from AMDEL site Averaging 160 ppm U
Media Type Desc2: –
Volume (L): –
Weight: 100 000 kg

SOURCE, TRANSPORT AND LOCATION

Transferred from: –
Consignee: –
Located into: One truckload into underground stope, rest along line of load?
Repository area: –
Transport dockets: –
Cartage Contractor –

REFERENCE AND VERIFICATION

File 1: SR 5/6/129
File 2: –
File 3: –
Confirmation of records: –
Photographic evidence: –
Diagram correlation: –
Reference 1: –
Comments: –

CONSIGNMENT 15

DATE

Date of Dispatch: 24/06/1998 –07/07/1998
Date of Deposit: 24/06/1998 –07/07/1998
Date of Burial: –

MATERIAL

Container Type: loose
Container Construction: –
Number of Units: –
Media: Soil
Media Type Desc1: –
Media Type Desc2: –
Volume (L): –
Weight: 192 000 kg

SOURCE, TRANSPORT AND LOCATION

Transferred from: Dry Creek?
Consignee: PPK
Located into: Into three open cuts
Repository area: –
Transport dockets: –
Cartage Contractor McMahon Services

REFERENCE AND VERIFICATION

File 1: 7033.002.003
File 2: –
File 3: –
Confirmation of records: –
Photographic evidence: –
Diagram correlation: –
Reference 1: –
Comments: –

CONSIGNMENT 16

DATE

Date of Dispatch: **03/07/1998**
Date of Deposit: **–**
Date of Burial: **–**

MATERIAL

Container Type: **200 L drum**
Container Construction: **–**
Number of Units: **63**
Media: **Soil/ Misc**
Media Type Desc1: **Low-level contaminated soil from Dry Creek site**
Media Type Desc2: **–**
Volume (L): **12600**
Weight: **–**

SOURCE, TRANSPORT AND LOCATION

Transferred from: **–**
Consignee: **–**
Located into: **Repository**
Repository area: **13**
Transport dockets: **–**
Cartage Contractor **McMahon Services**

REFERENCE AND VERIFICATION

File 1: **7033.002.003**
File 2: **–**
File 3: **–**
Confirmation of records: **Yes**
Photographic evidence: **–**
Diagram correlation: **–**
Reference 1: **–**
Comments: **–**

APPENDIX 6. REPORT AND SURVEY SUMMARIES

The following surveys, reports, papers and studies have been or are being undertaken in connection with the Radium Hill site:

SITE CHARACTERISATION

Dolan P.R. 1993. *Radium Hill Radiation Survey (7/12/1992).*

Purpose of survey was twofold: firstly to determine whether 7 piles of recently deposited waste material should be buried and secondly to determine if any other radioactive material was present on surface in the area that required burial. Part of the piles had elevated readings to 8 μGy/hr, and a number of other miscellaneous piles of waste rock etc were noted with levels to 7 μGy/hr. Authors note: it is believed this material was buried during maintenance rehabilitation activities undertaken in the same year.

Lottermoser, B.G. and Ashley P.M 2003. *Geochemistry and biogeochemistry of the Radium Hill uranium mine.* (Progress report)

'This project study aims were to assess the former mine site and town sites in terms of their current environmental status and hazards, and to assess physical and chemical dispersion of uranium, thorium and other deposit specific elements. In 2002 sampling and gamma-ray spectrometry were undertaken in the area. Gamma-ray data, plus stream sediment, soil, vegetation, crushed rock, waste rock and tailings samples were collected to assist in the examination of the current environmental status of the region.'

Authors note: An instance of misleading information was noted in an initial 'progress report' including an allusion to the radiation levels of soils and sediments being at or above Australian Radiation protection Standards, reported data did not support this assumption and a later abstract corrected this assertion.

A paper 'Ashley PM and Lottermoser BG (2004) Physical dispersion of radioactive wastes into regolith at the Radium Hill uranium mine South Australia' is to be presented at the 17th Australian Geological Convention in Hobart Tasmania.

McCarter H. 1981. *Radium Hill tailings dam — Tonnage calculations for bank and dam cover.* Unpublished report.

This report undertaken by H. McCarter (a vocational student at the time), calculated tonnages of material for a proposed cover design for the tailings dams. When comparing the proposed diagrams with what is understood to have occurred it appears that none of these designs were carried through.

AUDITS

EPA, 2003. *Audit of radioactive material in South Australia.* Radiation Protection Division. Environmental Protection Authority. Government of South Australia.

The audit applied only to radioactive material containing radionuclides with activity concentrations at levels regulated by the RPC Act and included radioactive tailings and residues at Radium Hill and Port Pirie, where Uranium ore was mined or processed in the past.

Resulting from this audit were a number of key recommendations including three relevant to the Radium Hill site, namely:

- 'That future management of South Australia's radioactive waste be in accordance with internationally agreed principles

- That regulatory control of sites containing radioactive waste be kept under review to provide an appropriate system for radioactive waste management for protection of human health and the environment.'

- That the government undertake a rigorous feasibility study of options for future management of South Australia's radioactive waste and that this study be commenced as soon as practicable.'

In addition, two general recommendations were made specifically related to the site:

- 'That long-term management plans be developed as required by conditions of registration of the Radium Hill site under the *Radiation Protection and Control Act 1982*.

- That the government develop options for management of the types of waste previously disposed of at the Radium Hill repository.'

PIRSA's present management arrangements and the Radium Hill – Port Pirie site characterisation study (this report forming phase 1) ensure the implementation of these recommendations.

SAICORP, 1996. *Radium Hill risk audit.* (Unpublished Report)

Mines and Energy SA requested SAICORP to investigate the Radium Hill workings and to report on the suitability of public safety measures and risk management activities undertaken to date. Various recommendations were made relating to access, fencing and signage, and hazard management.

Authors note: Some discrepancies were noted in this report.

GENERAL

Department of Mines (SA), 1954. *Filling of Stopes at Radium Hill.* Department Report DM 160/54

Preliminary investigations were undertaken to determine the need for filling and to consider suitable sources of fill including the use of sand filling utilising the tailings material. Quantity of filling required was estimated to be in the order of 40% of tonnage mined based upon Broken Hill figures.

Hill, P.R.H and Wilson, M.A, (n.d). *Low level waste repositories.* Unpublished Symposium paper (?), S.A department of Mines and Energy.

Believed to be a paper delivered in the early 1980's discussing the selection of sites for a low level waste repository, together with reasons and basic site description of why the Radium Hill site was chosen.

Sonter, M., 1998. *Visit to Radium Hill, 10 November 1998.* Unpublished report.

On 10 November 1998 a site visit was undertaken by M. Sonter to assess current site conditions including the measurement of gamma radiation levels. The report was summarised with:

'There is a need for a Site Environmental Management Plan, including a subsidiary Waste Management Plan, addressing all requirements to bring the site to an agreed level of final rehabilitation, over (say) the next 4 years. The remediation progress and ongoing checks as defined by the EMP need to be formally and regularly reported to CIM.

Completion of cleanup is thus recommended. However, in any cleanup, THERE IS NO POINT TRYING TO DECONTAMINATE an area of the South Australian outback that is NATURALLY RADIOACTIVE. Nor is it necessary to remove all and any radioactive material, no matter how innocuous. Note that probably all gravel on slight is slightly mineralised. Gravel paths in the townsite clearly are. But I DO NOT recommend their removal, because zero dose would be saved. One should not get caught attempting to render free of uranium a site that was and remains naturally radioactive. It is important, however to contain active sources of ongoing contamination, and to have a good record of 'what is where', and why.'

METALLURGICAL AND FURTHER PROCESSING

Appleby, W.R., Goscombe, P.W. and Thomas, A., 1961. Ore reserve estimate at 6th December 1961. *South Australia. Department of Mines. (unpublished). Report Book 675.*

In the absence of further contracts, production at Radium Hill ceased in 1961. The ore reserves at 6 December 1961, were estimated at:

	Tons	Grade	Lbs U_3O_8
Measured	49 647	2.4	121 297
Indicated	75 429	2.1	158 218
Inferred Category (A)	271 386	1.8	475 554
Inferred Category (B)	480 000	2.3	1 115 ,000

Hosking, P.K and Moskovits, E.E., 1960. Radium Hill tailings. Retreatment of dumps. Australian Mineral Development Laboratories. Report 40. *South Australian Department of Mines. Report Book 51/113.* (unpublished).

Initial tests of upper and lower layers of the flotation tailings dump. Recovery at the grade suggested by Radium Hill, namely 10lb U_3O_8/ton, was approximately 30 per cent. The amount of uranium circulating in the middlings products would be high. Followed by AMDEL report 64.

Sheridan, G.D., 1957. Extraction of rutile from leach residues of Radium Hill concentrate. Research and Development Branch. *South Australia. Department of Mines. (unpublished). Report No. R.D. 63.*

The residue obtained from leaching Radium Hill flotation concentrates contains rutile, haematite, ilmenite, silicates, and hydrolysed titania. Simple size classification followed by magnetic separation and flotation produced products containing 50 and 70 percent TiO_2 and representing overall TiO_2 recoveries of 14 and 44 percent respectively. Note further studies of extracting rutile were also undertaken with the Port Pirie residue.

Sheridan, G.D., and Hosking, P.K., 1960. Retreatment of Radium Hill tailings dumps. Australian Mineral Development Laboratories. Report 64. *South Australian Department of Mines. Report Book 51/114.* (unpublished).

Pilot plant tests were conducted of tailings material to confirm earlier laboratory tests. Results indicated that approx 0.95 lb of U_3O_8 were assayed in the lower level material. Estimated recoveries were between 31.7 and 65 %.

H EALTH

Woodward, A., Rodger, D., McMichael, A.J., Crouch, P. and Mylvaganam. A., 1991. *Radon daughter exposures at the Radium hill uranium mine and lung cancer rates among workers, 1952-87.*

'The aim of this historical (retrospective) cohort study was to investigate the relation between occupational exposure to radon daughters and subsequent mortality from lung cancer. Participants were former workers from the Radium Hill uranium mine, which operated in eastern South Australia from 1952 to 1961. A total of 2,574 workers were identified from mine records. Exposures to radon daughters were estimated from historical records of radon gas concentrations in the mine and from individual job histories. Exposures of underground workers were low by comparison with other mines of that period (mean 7.0 Working Level Months [WLM], median 3.0 WLM). Thirty-six percent of the cohort could not be traced beyond the end of employment at Radium Hill. Among those traced to the end of 1987, lung cancer mortality was increased relative to the Australian national population of the period (Standardized Mortality Ratio = 194, 95 percent confidence interval [CI] = 142-245). Compared with surface workers, lung cancer mortality was markedly increased in the underground workers with radon daughter exposures greater than 40 WLM (relative risk = 5.2, CI = 1.8-15.1). From the available information, we conclude that this increase is unlikely to be due to differences in smoking habits or other confounders. Taken together with the findings from other occupational studies, these results support current moves towards more stringent radiation control in the workplace, and underline the importance of research into the possible effects of domestic radon exposures.'

APPENDIX 7. CLOSURE OF FORMER MINE OPENINGS

Refer to Plan 2 for shaft locations based on the following Id letters.

Id	Name	Shaft & Mine Opening Covers etc 1962	Surface Insp 2001
A	Main Shaft 6800N	0.9 m heavily reinforced concrete at sub-brace	Backfilled and stable. Sealed OK
B	Smith Shaft 6900N	Filled with rough mullock — 61 m	Filled and sealed. OK
C	Brown Shaft 6600N	Filled with rough mullock surface to no.1 level	Filled and sealed. OK
D	6500N. Rise, Geiger	Filled with surface subsoil – surface to no.1 level	Stable, Filled & sealed. OK
E	6300N. Rise, Geiger	Surface to 4.6 m — rough mullock 4.6–6.7 m — reinforced concrete 6.7 m to no.1 level — open stope	Topped, Filled & sealed. OK.
F	Whip Shaft 6250N	Previously filled with mullock	Backfilled, mullock sealed. OK.
G	6132N. Rise, whip	'Golden stairway' — previously filled with rough mullock	Backfilled, Sealed. OK.
H	6050N rise/Winze	Surface to no.2 level – rough mullock – used as mullock pass	No problem. OK.
J	Ward Shaft	Previously filled with mullock	OK Sealed
K	5700N Rise	Previously filled with mullock	OK Sealed
L	5675N Rise	Previously filled with mullock	OK Sealed
M	Main Air Shaft 5500N	Surface to 4.0 m — rough mullock? 4.0–4.6m — reinforced concrete 4.6 m to no.4 level — open stopes and rise	Concrete Seal. OK.
N	Old Main Shaft	Previously filled with rough mullock	OK Sealed
S	5000N shaft	Surface to 6.1 m. — Rough and scrap. 6.1–7.6m reinforced concrete 7.6–9.1 m below no.4 level — open shaft	OK Sealed
T	3800N shaft	Slab of reinforced concrete on surface 4 x 4.6 x 0.6 m — open shaft to no.8 level. Timber pentice 4.6m below no. 7 level	OK Sealed
U	3070N. Watkins Winze	Slab of reinforced concrete on surface 4.6 x 3 x 0.6 m — open winze to no.5 level	
V	4600N. Winze South Hill extended	Surface to 19.8 m — bench stope to 7.6 m with rough mullock. Timber pentice at 19.8 m. 19.8 m to no.2 level — open winze.	
W	Main Orepass 6800N	Concrete placed on M.S plate door. 3 x 2.4 x 0.5 m. Most convenient access to M.S	Sealed and Intact 0.5 m
X	5100N Winze Dickinson	Surface to no.1 level filled with rough mullock	
Y	4950N Mullock Pass	Surface to no.2 level — rough mullock	Sealed and intact O.K
Z	3700N 3600N, South	Surface to no.2 level filled with rough mullock and surface soil — stoping to within 6.1-9.1 m below surface	Concrete slab at surface

APPENDIX 8. DRAFT GUIDELINES FOR LOW-LEVEL WASTE DEPOSITS

DEPOSITION OF LOW-LEVEL RADIOACTIVE WASTE AT THE RADIUM HILL WASTE REPOSITORY

Procedures to be followed include:

A. Company

- A written request for approval to deposit waste is made to the Minister/ Chief Inspector of Mines (CIM).
- Details of the quantity and type of materials to be provided to the CIM including gamma readings.
- All equipment to be made unserviceable before disposal.
- Loose material to be drummed before disposal.

B. Mining Operations Branch

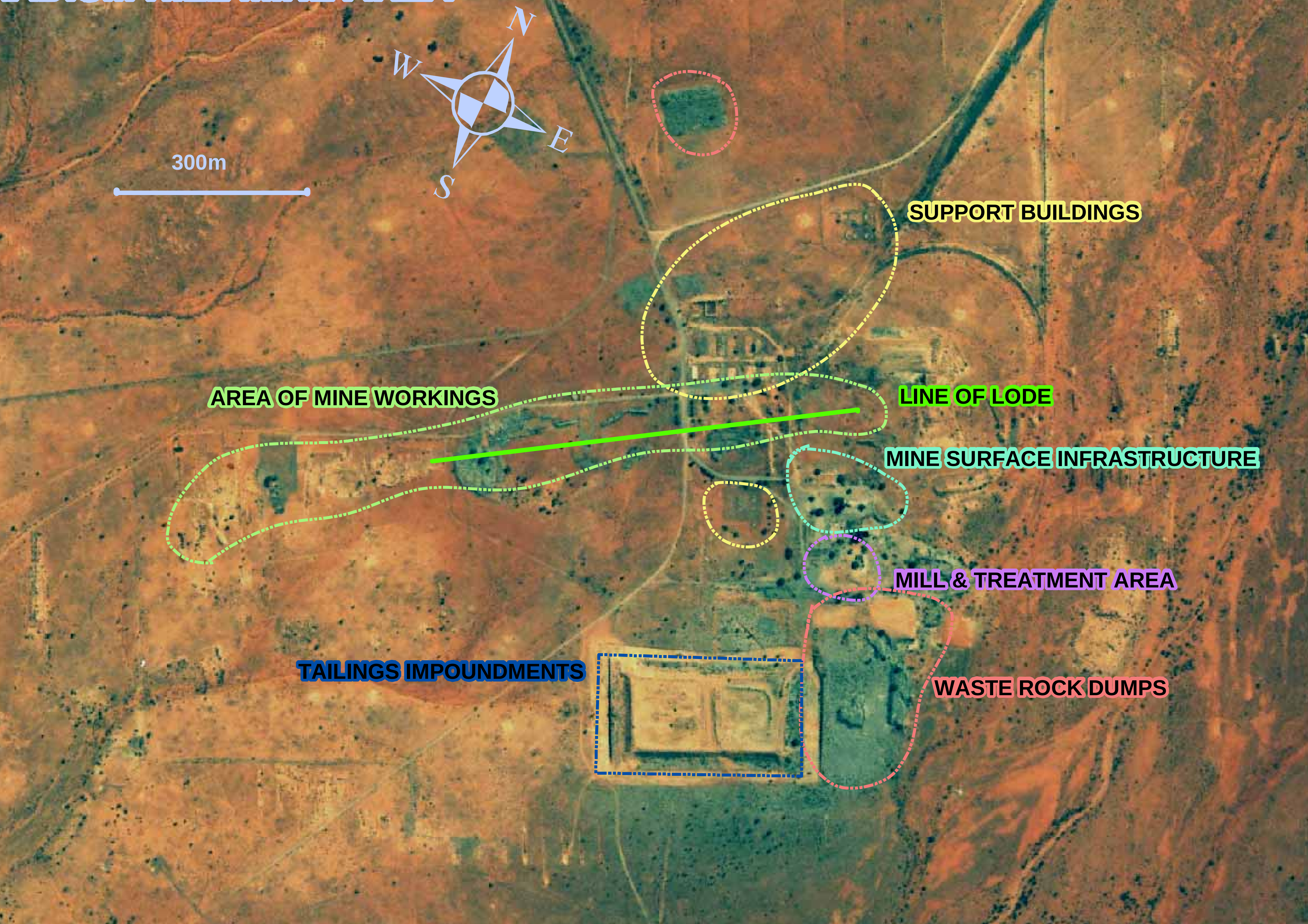
- To agree on the date and time of delivery with the company.
- To specify the area for deposition
- To supervise the deposition and covering of the material.
- To plot the area of deposition and record the contents and date.
- To estimate the cost of disposal and advise accounts section who will send an account to the company.
- Advise South Australian Health Commission (ed. Note now EPA) of the deposition and provide a copy of the report.
- Prepare a report (copy to SAHC) to include:
- Quantities and types of materials deposited
- Location plan, including photographic record
- Results of a gamma survey before and after disposal

APPENDIX 9. DAVIDITE – (LA) DATA

Information sourced from the 'Mineral database' and the 'Mineralogy database'.

Davidite (La)	
Formula: $(La, Ce)(Y,U,Fe)(Ti,Fe)_{20}(O, OH)_{38}$	
Physical Properties	
System: Trigonal	Colour: Black
Lustre: Vitreous	Hardness: 6 Orthoclase
Density: 4.42	Streak: Brownish Black
Cleavage: None	Diaphaneity: Opaque
Fracture: Brittle - Conchoidal - Very brittle fracture producing small, conchoidal fragments.	Habits: Massive - Uniformly indistinguishable crystals forming large masses., Anhedral Grains - Granular minerals without the expression of crystal shapes, Metamict - Mineral originally crystalline, now amorphous due to radiation
Composition	

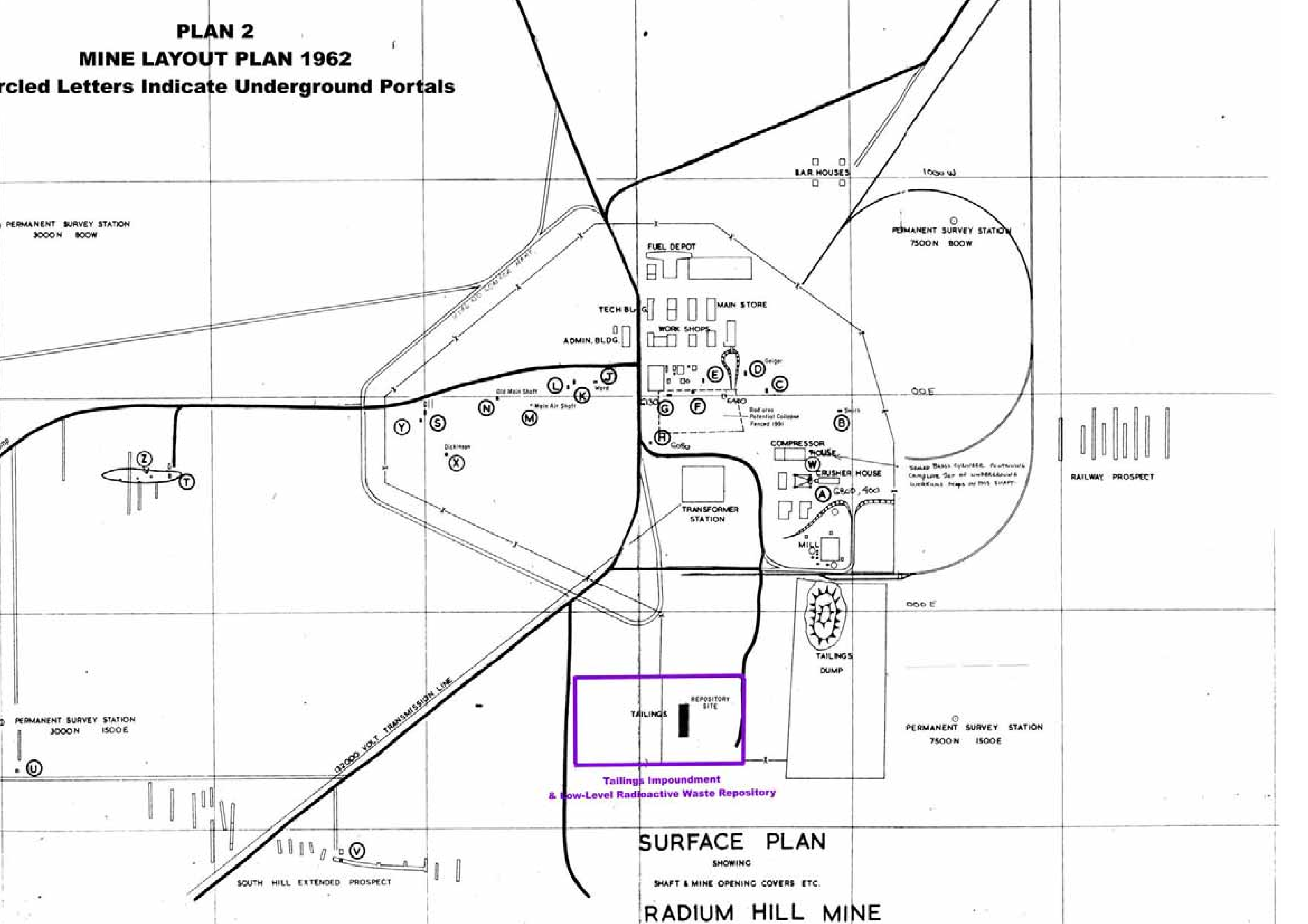
Calcium	0.22 %	Ca	0.30 %	CaO
Lanthanum	5.23 %	La	6.13 %	La_2O_3
Cerium	1.51 %	Ce	1.76 %	Ce_2O_3
Yttrium	3.58 %	Y	4.55 %	Y_2O_3
Uranium	3.20 %	U	3.63 %	UO_2
Titanium	38.59 %	Ti	64.39 %	TiO_2
Iron	15.01 %	Fe	21.45 %	Fe_2O_3
Oxygen	32.67 %	O		
	100.00 %		102.21 %	= TOTAL OXIDE

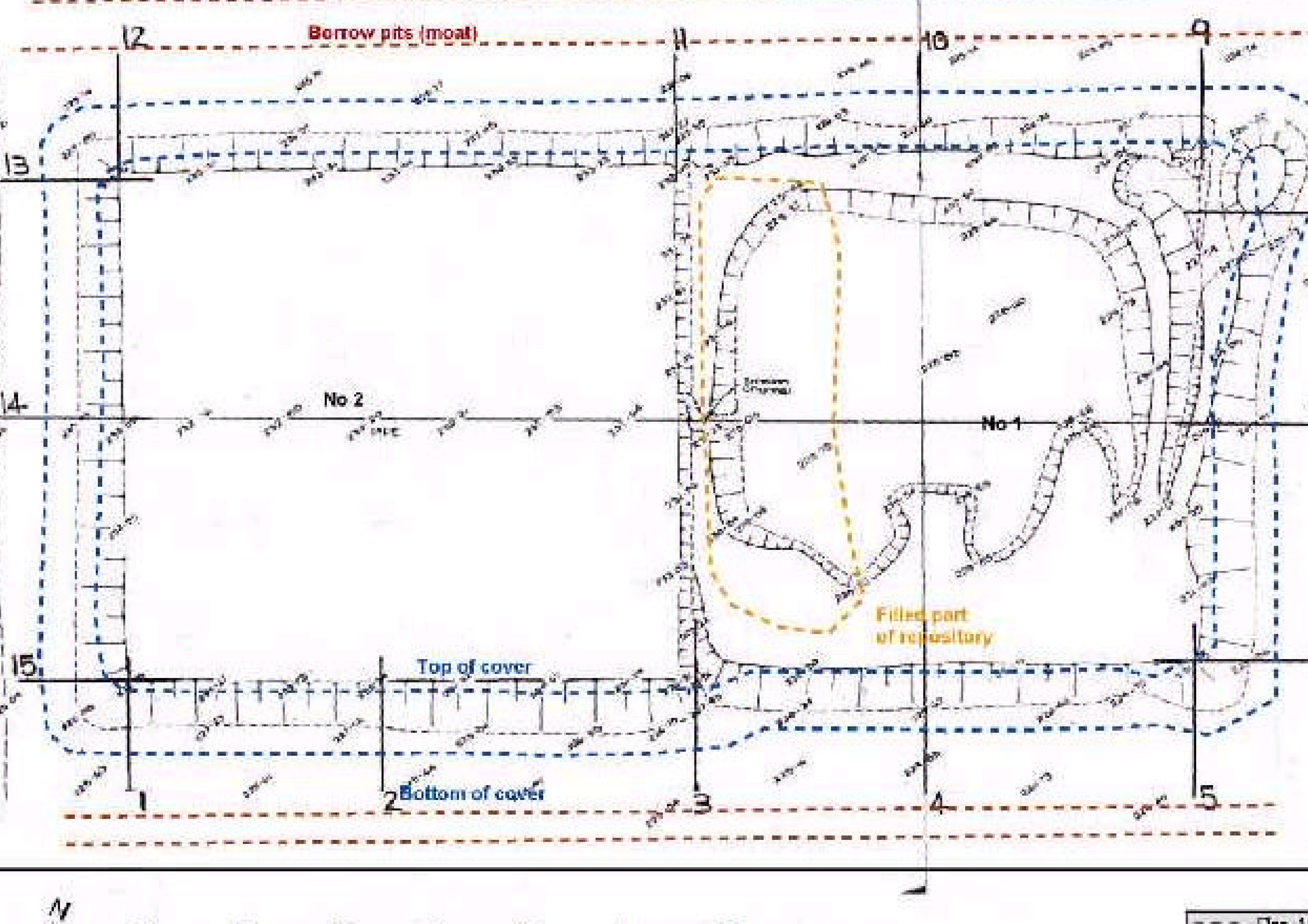

N
W
E
S
300m
SUPPORT BUILDINGS
AREA OF MINE WORKINGS
LINE OF LODE
MINE SURFACE INFRASTRUCTURE
MILL & TREATMENT AREA
TAILINGS IMPOUNDMENTS
WASTE ROCK DUMPS

PLAN 2

MINE LAYOUT PLAN 1962

rcled Letters Indicate Underground Portals





Borrow pits (moat)
12
11
10
9
13
14
15
No 2
No 1
Top of cover
Bottom of cover
Filled part of repository
1
2
3
4
5
N