Cameco

Yeelirrie Tailings Storage Facility Design and Management

Yeelirrie

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Geo-environmental Engineering, SHEQ, Environmental Affairs

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1 Introduction

The Yeelirrie project is located in the East Murchison region of Western Australia, approximately 70 km south-west of Wiluna and 55 km to the east of the Mt. Keith mine.

The proposed project would recover uranium from carnotite ($K_2(UO_2)_2(VO_4)_2).3H_2O$), a uranium-vanadium mineral phase, in association with calcrete and clay sediments from a shallow deposit. The ore body has a strike length of approximately 9 km with an average width of 1 km. The deposit extends down to about 8-10 m below surface while the groundwater table occurs about 5 m below the natural ground surface.

The project area is underlain by weathered Archaean Granite. Overlying the granite are valley-fill deposits from a former river system (palaeochannel). The central drainage channel in the vicinity of the orebody is comprised of four principal lithological units based on exploration drilling and trial pitting in the 1970s.

- Overburden: A mixture of sandy loam, siliceous and ferruginous cemented hard pan and carbonated loam.
- Calcrete: A calcite and/or dolomite replacement of the clay-quartz (of varying width, thickness and texture). Approximately one quarter to one third of the uranium mineralisation is located within the calcrete.
- Clay-Quartz: A kaolinitic clay-quartz and alluvial material that contains over 60% of the uranium mineralisation. The highest grade U mineralisation is located just below the water table in the clay-quartz zone.
- Archean Granitic Basement Complex is present around 30-60 m below ground surface in the vicinity of the ore body.

Tailings from processing of Yeelirrie ore will be deposited back into the mine void below ground level. The Yeelirrie in-pit TSF will cover an area 6.5 km long and 1 km wide and will be approximately 1 km from the mill. In the mine plan the pit is divided into 2 tailings ponds each consisting of 5 individual cells of varying sizes ranging from 229,437 m^2 to 358,751 m^2 (23-26 hectares). Tailings pond 1, comprised of five individual tailings cells will be operated first. Tailings cells will utilise sub-aerial, thin layer deposition of tailings slurries and use evaporation to dewater and consolidate the tailings.

Development of the project proceeds from mine dewatering to mining and then to milling and tailings deposition to closure. At the start of milling, one tailings pond (5 tailings cells) must be prepared and three of those tailings cells operationally ready for tailings deposition, including compacted floor, pit wall embankments and any drainage requirements.

This appendix serves as an extension to the Project Description, of the PER, providing additional detail on the design and management of the proposed Tailings Storage Facility (TSF). For a general description of the proposed Yeelirrie development refer to the PER. Beyond describing the TSF, this appendix provides a brief review of the regulatory requirements and industry guidelines applicable to TSF design and operation.

The TSF design for the proposed Yeelirrie development commenced with work completed by WMC in the 1970s, and this appendix provides an overview of the TSF design-related investigations completed from that time to the present. This appendix also provides an indication of the operating parameters for the proposed TSF, and the considerations of specific note in respect of in-pit tailings disposal.

1.1 Mine and Milling Plan

A primary driver of the mine plan and schedule is the in-pit disposal of tailings. The shallow depth of the pit floor allows for the rapid development of both tailings space and stockpiles of material of appropriate uranium grade and geo-metallurgical parameters.

The mine plan includes a dewatering schedule, mining and milling and progressive rehabilitation of the tailings disposal. At the design production rate of 2.4 million tonnes per year (Mtpa) the life of mine is estimated at 22 years including dewatering, mining, milling and rehabilitation.

Stockpile management will be an important activity as ore will be mined in advance of milling to create tailings space. Ore will be characterised into 5 categories (ultra high grade (UHG), very high grade (VHG), high grade, (HG), medium grade (MG) and low grade (LG)) and each category divided into a low and high smectite grade (the low grade stockpile will only have one smectite grade), for a total of 9 ore stockpiles (see “Development of Tailings and Mine Waste Source Terms for the proposed Yeelirrie Mine”).

The processing plant is designed to treat Yeelirrie ore at a rate of 2.4 Mtpa with a uranium feed grade that averages approximately 0.15 % U_3O_8. The processing plant will utilise a high temperature alkali leach process followed by direct precipitation to produce uranium oxide concentrate. Uranium processing would require leaching of the ore using sodium bicarbonate/carbonate. This would result in as-discharged tailings with a pH of about 9.5 and a high total alkalinity (>75,000 mg/L $CaCO_3$). The mill discharge slurry is projected to have a solids content of approximately 40%.

1.2 Tailings Disposal

The primary disposal concept is that the tailings would be deposited sub-aerially directly into beached (1% slope) TSF cells located in the mined-out pit. Internal berms would be constructed of compacted tailings (if the material proves suitable and if it is available), or other appropriate fill material. Embankments contacting the pit wall would be constructed of silty-clay, which are abundantly available on site as the substrate to the mined ore. Tailings water would be recovered from the TSF via a central decant in each of the TSF cells. The return water system will be enhanced by under-drainage as required. Recovered water may be directed through the external evaporation ponds if further solids control is required prior to re-use in the plant.

Tailings will be deposited in thin layers and restricted to a rate of rise of consolidated tailings of 1.2 m per year. This value represents a conservative estimate for effective consolidation, based on field and laboratory observations for the environment at Yeelirrie. Thin layer deposition requires that tailings be deposited in rotation. Each tailings cell will be filled for a period of approximately six days. Tailings deposition will then move to the next tailings cell such that there is a consolidation period of about 24 days before tailings are again deposited in the first tailings cell.

There will be a total of 10 tailings cells over the mine life operated in two tailings ponds. Tailings will be deposited in pond 1 from the start of milling for about 7 – 8 years and then move to pond 2 for a similar period (section 8.5). Capping of tailings cells and other reclamation activities will begin after the filling of pond 1. Five tailings cells will be operated simultaneously with internal embankments constructed of compacted tailings, and/or other fill. In order to separate the tailings from the natural groundwater, embankments contacting the pit wall will be constructed of silty clay sourced from on-site.

Current maps indicate that the calcrete extends around the proposed in-pit tailings facility. After closure this will provide a continuous preferred, high transmissivity groundwater flow path around the tailings from west to east around the tailings. Groundwater flow modelling of the closure flow regime shows that the disturbance to the long term water table configuration is moderate and no additional engineering control measures will be necessary.

2 Proposed Tailings Storage Facility

The proposed development requires the excavation of an open pit mine to extract uranium- bearing ore from the Yeelirrie ore body. The proposed pit would use surface mining equipment (conventional truck and shovel) to remove the ore and overburden, which would be placed in stockpiles surrounding the open pit.

Mining would start approximately a year in advance of metallurgical plant operations so as to provide sufficient area for the construction of the first in-pit tailings storage cells within the open pit that would provide sufficient storage capacity for the first tailings produced. As mining progresses, additional tailings cells would be constructed in the mined-out void. The mining plan ensures that the proposed project would always have sufficient mining void capacity for the construction of new TSF cells well ahead of when they are required for tailings storage (about 3 years) and would ensure that a TSF would never be required outside of the pit. It is anticipated that at the start of milling, only 3 tailings cells would be available for tailings deposition but within approximately 6 months the remaining two tailings cells in tailings pond 1 would be operational. The reduced production in the first year of milling as the mill is being ramped up to full production ensures that the target rate of rise can be achieved even with only 3 tailings cells operational in the first year.

In mining the pit, drainage channels would be established in the pit floor to facilitate dewatering of the clay. These may be used as underdrains as the TSF cells are constructed if additional consolidation of the tailings is required. However, it should be noted that little or no seepage is expected for reasons explained later in this appendix. In order to aid in the understanding of tailings consolidation, instrumentation (such as vibrating wire piezometers) will be added to the early TSF cells.

Over the life of the project, approximately 10 cells would be built within the pit void allowing for the permanent storage of around 2.4 Mtpa of tailings material. The cells in the first tailings pond would have an average area of about 309,000 square metres (31 hectares). It is anticipated that three to five cells would be operated simultaneously at any given time during the project life, using their combined area to maximise the speed of drying of newly deposited tailings.

The embankments, keyed where necessary into clay, would be built to a height of around 1 m below the original ground level. They would be built to full height prior to commissioning, and not constructed in stages or ‘lifts’ as is common practice on other mine sites. Once commissioned, each tailings cell would be filled with tailings such that the tailings surface would vary from about 1m below natural ground level at the embankment, to approximately 3 m below the original ground level in the centre of the cell. The average depth of the deepest tailings cell would be around 8 m. Each TSF cell would take about seven years to fill at an average rate of rise of 1.2 m/year.

The embankments (designed as water retaining structures) would safely separate the tailings from the active mining areas and the pit wall. The TSF embankment would be built directly against the pit wall. A permanent drain between the pit wall and the TSF embankment would direct any surface water inflow to the pit into the dewatering system and away from the TSF embankment.

Tailings would be deposited into each TSF cell in a continuous two-phase cycle; a tailings deposition phase and a drying phase, rotating deposition between five cells so that each cell has a drying time of 24 days (end of filling to beginning of deposition in next cycle). During the tailings deposition phase within each TSF cell, as the tailings solids are left on the TSF beach, the tailings water would report to the centre or low point in the cell forming a small temporary pond.

Water would be retrieved from the pond by a decant system or floating pump system and returned to the metallurgical plant for reuse possibly through a settling pond. When the cell is full, the bottom of the central pond would be significantly lower than the sides of the cells. Given that the water is efficiently returned to the metallurgical plant, and in the absence of significant rainfall events, it is likely that the pond would dry out completely in the drying phase – similar to the clay pans found in the area. As a result, the cells would not have an internal water table mound as found in traditional ring-dyke TSF cells common at many mines, where the central pond is a permanent feature, rising to some 25 to 30 m height above the cell floor. Instead the tailings will partly re-saturate after dewatering from adjacent mine blocks is discontinued.

During the operational life of the proposed TSF cell, the mandatory beach freeboard (0.3m) and the basin formed by the tailings beach would ensure sufficient freeboard and storage capacity at all times to contain the specified design rainfall event. In addition water could be directed to the external evaporation pond (approx. 29.5 hectares) if further water control is required.

Once filling with tailings has been completed, the resultant ‘bowl’ or depression left in the centre of each TSF may be filled with further tails using central discharge techniques prior to decommissioning the cell (alternatively the bowl may be filled with overburden material). Overburden material stockpiled during mining would be used to cover decommissioned tailing cells. This cover material would be shaped to provide a shedding profile with reduced permeability, reduced radon exhalation and a surface suitable for re-vegetation. It is anticipated that the total depth of cover would not be less than 2 m.

The covering of the TSF cells with overburden would commence as soon as the dried tailings surface within each completed cell is sufficiently solid and dry to permit safe traffic of earthmoving equipment. At the proposed average rate of rise of around 1.2 m/year, little if any consolidation is anticipated after the cell has been decommissioned, and the TSF surface would be accessible and trafficable by earthworks equipment within a year after tailings deposition has ceased.

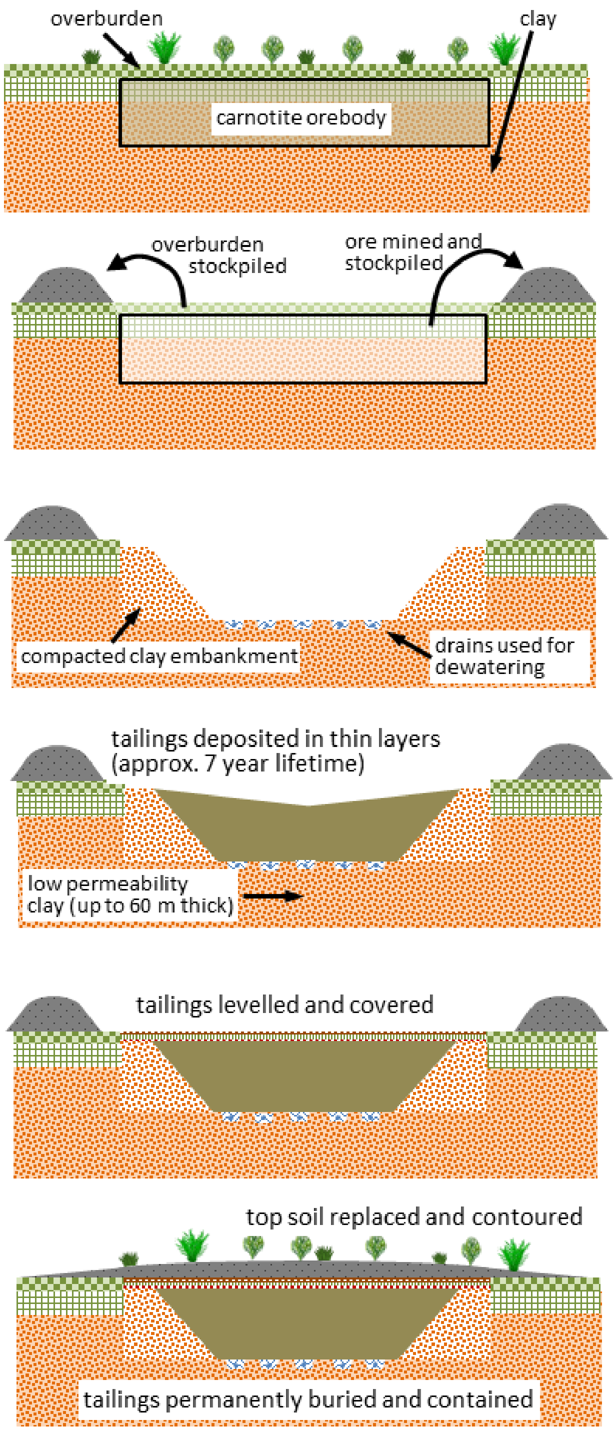


Figure 2.1 Schematic of tailings cover design. Low permeability clay-quartz underlies the tailings storage facility (TSF).

Further to the storage of tailings, all material mined from the pit that is not processed during mining operations, and contaminated infrastructure that would not be removed from site, would be backfilled into the pit voids. As a result, there would be no above-surface mining features such as waste rock stockpiles or plant, or a pit void, post-closure. The backfilled pit would be covered with overburden materials specifically identified and stockpiled for use as the final exterior cover.

The in-pit TSF construction sequence from mining through to closure is illustrated schematically in Figure 2.1.

3 Regulatory Requirements and Guidelines

The Legislative Framework of the PER provides an overview of the legislation relevant to the proposed Yeelirrie development. This section provides information specific to the requirements for tailings.

3.1 Uranium tailings disposal and design standards

Cameco is committed to statutory compliance and adherence to recognised industry standards. Additionally, it should be noted that Cameco’s compliance ensures an additional likelihood of containment integrity as most of the referenced standards relate to above ground storage facilities and not in-pit storage methods as proposed herein. The TSF design process was conducted primarily in consideration of the following regulatory codes and guidelines as minimum design standards.

3.2 Guidelines for tailings storage in Western Australia

For all mining projects in Western Australia, a TSF design report is to be produced in accordance with Guidelines on the Safe Design and Operating Standards for Tailings Storage (DME (WA) 1999) (hereafter referred to as the DME Guideline). In the event that the proposed Yeelirrie development obtains the requisite environmental approval (i.e. project approval via the PER process), a TSF design report will be submitted to the DME as part of the subsequent and various other approval processes. The design report is subject to approval by the WA Department of Mines and Petroleum, and thereafter the TSF is to be constructed in accordance with the approved design.

It is noted that this appendix is not the full TSF design report.

The intent of the DME Guideline is to provide a common approach to the safe design, construction, operation and rehabilitation of TSFs, and to provide a systematic method of classifying their adequacy under normal and worst-case operating conditions. The design and operating requirements are based on a hazard rating and TSF category as outlined in the Guideline.

By virtue of the nature of radioactive tailings, the Yeelirrie tailings storage facility has been designed in accordance with a ‘high’ hazard rating, requiring design, construction and operational aspects to be addressed in compliance with the Guidelines for a Category 1 TSF. Category 1 TSFs require the highest standard of design, operation and monitoring.

The Guidelines also:

- Recommend aspects to be addressed in construction documentation, periodic audits and reviews, and pre-decommissioning reviews.
- Provide recommendations for operational standards for tailings storage facilities including deposition methods, deposition principles and the daily operation of a TSF to an appropriate standard in accordance with an operating manual tailored in content to suit the TSF. For the operating manual, a detailed list of operating manual contents is given in the Guidelines on the Development of an Operating Manual for Tailings Storages (DME (WA) 1998). In addition, once approvals have been obtained (including a Works Approval from the WA Department of Environmental Regulation) the TSF owner is required to submit:
- A tailings storage data sheet (standard template provided in the Guideline – completed for approvals process).
- A certificate of compliance that the tailings storage facility design has been designed in accordance with the current edition of the Guidelines on the safe design and operating standards for tailings storages issued by the Department of Minerals and Petroleum, Western Australia and the design is referenced.
- A certificate of compliance – a statement providing notice that the tailings storage facility construction has been constructed in accordance with the approved design and the guidelines on the safe design and operating standards.

3.3 Australian requirements

3.3.1 ARPANSA Mining Code

The Yeelirrie tailings would contain a low concentration of radioactive materials – approximately 50 to 150 ppm uranium and other radionuclides. The disposal of radioactive tailings in Australia is regulated by the Australian Radiation Protection and Safety Agency (ARPANSA) under the Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005) (ARPANSA 2005). The Code of Practice, also known as the Mining Code, provides the guideline for radiation safety in the mining and mineral processing industries.

With regard to TSFs, the Code requires the proponent to demonstrate that they have designed and constructed the TSF to a standard that achieves an appropriate level of radiological control using best practicable technology.

The Mining Code requires that approval should be obtained from the relevant regulatory authority for the Radiation Management Plan and the Radioactive Waste Management Plan prior to the commencement of any stage of an operation to which the Code applies. In Western Australia, the relevant regulatory authority is specified in the Code Annexure A as the State Mining Engineer, Resources Safety Division, Department of Mines and Petroleum. Authorisation for the construction, operation, closure and rehabilitation steps are also required, in parallel with other requirements for approvals or authorisation in accordance with other applicable regulatory and or legislative requirements.

3.3.2 ARPANSA guidance documents

While not forming part of the regulatory framework for the Yeelirrie tailings storage design, ARPANSA provides a series of guidance documents to be used in developing the proposed TSF. These are:

- Scientific Basis for the Near Surface Disposal of Bulk Radioactive Waste. Technical Report
- TR No 141. (ARPANSA 2005b)
- Code of Practice for the near-surface disposal of radioactive waste in Australia (1992), Radiation Health Series RHS No 35, 1992

3.4 Other Guidance Material

The following guidance documents were also referenced in developing the TSF design. These documents do not form part of the regulatory framework for the Yeelirrie tailings storage design, but nevertheless provide valuable information, key considerations, and criteria against which the Yeelirrie tailings storage design can be evaluated. They are:

- Guidelines on Planning, Design, Construction, Operation and Closure of Tailings Dams (ANCOLD (2012).
- Guideline for Tailings Management, Department of Industry, Tourism and Resources, February 2007 (DITR, 2010).

4 Best Practice design

Cameco is committed to best practice design in radioactive tailings management. The TSF for the proposed Yeelirrie development is designed to:

- comply with all applicable regulatory requirements (see Section 3 of this appendix) for the safe storage of tailings, both during operation and in the long-term post-closure

- satisfy all applicable tailings design codes and standards
- accommodate mining and processing plans for the entire life of the project
- incorporate features that aid the progressive closure of individual TSF cells
- ensure effective erosion control and viable substrate for revegetation
- effect the long-term isolation of tailings solids
- control the release of water from the TSF both during operations and post-closure such that released water causes no impacts beyond those predicted in the impact assessment
- produce a final landform that is safe and stable.

The proposed leading practice design will ensure that:

- the radiological exposure of people and non-human biota would be well below applicable limits
- the release of radioactive and other contaminants into the soils, rocks and groundwater underlying or adjacent to the TSF is restricted
- the release of fugitive dust from the tailings surface is minimised, and that such emissions if they occur (which is not anticipated), are at rates or in quantities that could not cause harm to humans or other non-human biota
- all aspects of the design satisfy Cameco's internal standards (known as 'group level documentation' or GLDs).

4.1 Benchmarking

As discussed in the PER, Cameco examined a number of alternative tailings disposal options before selecting the in-pit proposal as described in Section 2 of this appendix.

A benchmarking study on leading practice in-pit tailings disposal was completed by Golder Associates (Yeelirrie In-pit Benchmarking Study (Golder 2010). Numerous similar tailings options studies have been completed for Cameco's facilities in northern Saskatchewan, Canada, by Golder and SRK Consulting. Based on Golder's study and other independent expert evaluations, a benchmarking assessment of risk factors can be listed:

- Seepage
- Radiation
- Dust generation
- Spillage
- Flooding
- Closure.

The manner in which the proposed design addresses these risks is discussed in Section 7. The Golder report concludes that the proposed Yeelirrie design concepts achieve leading practice on all six areas of risk identified for this site and that:

- In-pit disposal of uranium tailings is considered to be leading practice management.
- Existing deep residual clays are likely to provide a very effective barrier against seepage loss.
- The philosophy of maintaining a moist beach surface during operation is leading practice (for radon emanation control).
- Surface water management by diversion and containment during operation, and low flow net collection areas for post-closure (to control erosion), are considered to be leading practice.

5 Existing Environment

5.1 Climate

The Yeelirrie project site is located in a sub-tropical semi-arid region, with long hot dry summers and cool dry winters. Summer rainfall is associated with tropical weather systems, including rain-bearing depressions originating as cyclones and with winter frontal systems. Rainfall is highly irregular at all time scales and monthly totals are highly variable from year to year. High intensity rainfall can occur at any time of year. The climate is described in further detail in the relevant PER section.

Rainfall and evaporation statistics are a key component of TSF design and hence the overall plant water balance. The most reliable monthly and annual average rainfall and evaporation data are BoM generated synthetic data based on gridding of selected, processed observed regional records (SILO data). Those records are shown in Table 5.1 and are used in the TSF basis of design.

Table 5.1 Mean monthly Yeelirrie Rainfall and Evaporation

Month	Monthly Mean (mm)		
	Precipitation	Evaporation	Net loss
Jan	26	418	392
Feb	29	331	302
Mar	30	293	263
Apr	24	200	176
May	24	132	108
Jun	25	90	65
Jul	17	98	81

Month	Monthly Mean (mm)		
	Precipitation	Evaporation	Net loss
Aug	12	136	124
Sep	4	201	197
Oct	7	288	281
Nov	8	341	333
Dec	17	392	375
Annual	223	2,920	2,697
Period	1889-2010		

5.2 Geology

The regional geology of the Yeelirrie site is dominated by Archaean granites that have been subjected to prolonged weathering and erosion. Layered over the granites are valley-fill deposits in an ancient palaeochannel. The project area is immediately underlain by alluvial clays interspersed with sandy lenses deposited in the Quaternary period and further below by dense lacustrine palaeochannel clay deposits about 30 to 35 m thick. The total depth of clay soil underlying the ore deposit and the proposed tailings storage facility is approximately 30 to 60 m in thickness.

Table 5.2 (reproduced from Appendix A of the "Development of Tailings and Mine Waste Source Terms for the Proposed Yeelirrie Mine") summarises the twelve lithological types identified in Yeelirrie logs. Calcrete formation is hypothesised to have taken place over a long period of time through the mobilisation of carbonate and subsequent precipitation downstream. The geology of the area is further described in the Geology, section of the PER

Table 5.2 Lithological types found at Yeelirrie

Lithological Type
Hardpan – H
Carbonated hardpan – HT
Loam – L
Quartz-rich loam – LQ
Carbonated quartz-rich loam – LQT
Carbonated loam – LT (ore-bearing)
Calcrete – T (ore-bearing)
Transition calcrete – TCQ (ore-bearing)
Carbonated clay-quartz – CQT
Arkosic clay-quartz – CQA
Clay-quartz – CQ
Granite – G

5.3 Surface water and Groundwater

The Yeelirrie ore deposit is situated at the valley floor within the upper Lake Carey Catchment, which drains east and southeast via a series of salt lakes including Lake Miranda and Lake Darlot. Surface flows vary from brief ephemeral flows in steeper channels on the valley slopes to rare broad, central valley flood wave discharge via sheet flow and short ill- defined braided channels at the valley floor. The latter, large scale flood flows, resulting from rare high intensity and long duration rain events (such as tropical rain bearing depressions) are of relevance to TSF design.

There is little by way of observational records to determine peak flood levels and these have been determined by un-calibrated run-off routing and hydraulic models using conservative regionally based assumptions. The results have been used to design perimeter waste rock dumps and bunds which isolate the pit and TSF from the catchment flood wave (see URS 2011b).

The shallowest groundwater system is within the superficial formations including the calcrete (orebody), clay-quartz and marginal alluvium along the sides of the valley. As already indicated, the water table aquifer is separated from the deeper aquifers by clays up to 60 m in thickness.

Groundwater is addressed in the PER (see “Numerical groundwater flow and solute transport model of the Yeelirrie uranium deposit”).

Extensive surface and groundwater investigations were undertaken by WMC Resources (WMC) in the 1970s and early 1980s. The historical hydrogeology information of the Yeelirrie area is summarised in the Environmental Impact Statement (1978) and Yeelirrie Project Groundwater Investigation Phase 3 (1981).

5.4 Seismicity

A seismic hazard evaluation was carried out for the Yeelirrie site using earthquake source zones within 800 km from Yeelirrie. Seismic attenuation models were used to predict frequency, magnitude and bedrock accelerations of earthquakes at Yeelirrie and this data was then used to define the seismic parameters for use in stability analyses of the tailings embankment slopes.

This data is then used to define the seismic parameters for use in stability analyses of the tailings embankment slopes.

Table 5.3 Seismic design peak ground accelerations

Earthquake design case	Return Period or Average Recurrence Interval (ARI)	Peak Ground Acceleration (PGA)
Operating Basis Earthquake (OBE)	1,000 years	0.072
Design Basis Earthquake (DBE)	5,000 years	0.11 g
Maximum Credible Earthquake (MCE)	> 10,000 years	0.25 g

The peak ground accelerations for ANCOLD 2012 design earthquake cases are listed in Table 5.3.

In this study, the preliminary pseudo-static slope stability analyses for the in-pit embankments use an equivalent pseudo-static lateral acceleration coefficient of 1.0 PGA.

6 Tailings Storage Facility (TSF) Investigations

This section describes historical geotechnical and geochemical investigations dating from the early 1970s to the most recent laboratory tests.

6.1 SRK Tailings Investigations

Geochemical assessment for the Yeelirrie project was carried out in 2010 by SRK Consulting. Two documents were produced,

- Proposed Yeelirrie Development: Geochemical Assessment of Tailings and Mine Waste, Issued: 10 March 2011, Project code: BHP047/1
- Proposed Yeelirrie Development: Assessment of Tailings and Mine Waste Source Terms, Issued: 10 March 2011, Project code: BHP047/2

The listed objectives of these studies were to:

1. Assess the potential for solute release from tailings in the short and long term;
2. Determine the potential interaction between the solutes and the natural geological materials downstream of the mine facility;
3. Evaluate the chemical composition of materials (ore, waste, and topsoil) to be stockpiled on site and assess the loadings that may be released from the materials.

Pilot plant tailings samples and underlying sediments were collected from the historic Kalgoorlie Research Plant tailings storage facility. In addition, fresh tailings slurries were aged for up to eight months in duplicate in either open (simulating atmospheric conditions) or sealed (simulating anaerobic conditions) flasks. Leaching experiments, using de-ionised water and barren process liquor, were also performed.

6.2 WMC Studies and Previous Mining Trials at Yeelirrie

Between the mid-1960’s and early 1990’s, WMC Ltd (originally Western Mining Corporation Ltd) undertook a series of studies and investigations at the Yeelirrie site and at the associated Kalgoorlie Research Plant to gain further knowledge on the characteristics of tailings likely to be produced as a result of mining and processing the Yeelirrie ore.

Trial mining of 3 small pits was completed between 1971 and 1982, with selected ore samples being transported to the Kalgoorlie Research Plant (KRP) for processing trials. The tailings from these trials were deposited in a void excavated at KRP.

The operation and closure of these sites provided information useful in developing designs for the proposed Yeelirrie development. In particular:

- The disposal, storage and covering of tailings at the KRP site provides data on the behaviour of the tailings, settlement of the tailings under cover loads, the potential for solute migration away from the tailings, and the behaviour of the solutes when interacting with the nearby host rocks.
- The three trial pits at the Yeelirrie mine site provided ‘real world’ data about groundwater inflows during mining, the behaviour of the mined materials and the base of the proposed pit, the physical properties of potential construction and cover materials, and the stability of the pit slopes. Further, the trial mining provided the then operator with the opportunity to test various water management options.
- Site inspections in 2004 of the ore and overburden stockpiles that were left in place after the cessation of WMC’s test mining provided information on:

    - The erosion and dispersion of solids from the overburden and ore stockpiles when exposed to normal and extreme meteorological conditions (e.g. cyclone Bobby in 1995). It is noteworthy that materials mined from Trial Slot 1 were stockpiled for 31 years, yet the tailings solids eroded from the stockpiles remained within tens of meters of the stockpile toe.
    - The absence of any detectable effect of the stockpiled material, eroded material or leached metals on nearby vegetation. In fact in many instances native vegetation had started to colonise the

stockpiles prior to the completion of rehabilitation earthworks in 2004.

- The water infiltration and suction behaviours of the near surface materials. For example, vegetation regrew adjacent to and in the trial pits (i.e. close to the near-surface water table) indicating that the surface soils do not readily transfer salts from the water table to root zone of the plants in question.
- The 2004 rehabilitation of the WMC workings, as documented in the closure project records and the annual environmental functional analysis (EFA) reports provided to the State, provide valuable data and observations on:

  - the methods of backfilling the trial mining areas and the materials used
  - the effectiveness of re-established subsoils and soils
  - the effectiveness of the revegetation effort
  - the behaviour of the surface cover in terms of erosion resistance and its general performance when subject to surface flooding – both under storm and lesser events
  - the effectiveness of the cover in terms of reducing radiation emissions from the buried waste

During the 1970s and 80s, various drill holes and site excavations took place in order to provide material suitable for metallurgical testing and for investigation into possible mining strategies.

Prior to rehabilitation in 2004, samples from pits, stockpiles and undisturbed soils were obtained. Sample pH values ranged from 6.8 to 9.7, with the majority of samples yielding alkaline pH values greater than 8.

Gamma radiation surveys took place before and after rehabilitation on stockpiled materials used to backfill test pits. Readings differed significantly on stockpiled material before and after closure, up to 45 µS/hr readings were obtained before and readings less than 1.5 µS/hr were obtained after rehabilitation. The low readings in areas after removal of stockpile material suggest there was limited or no release of radionuclides from the stockpiles during their lifetime (20 to 30 years). The release of other solutes was not determined during this period. (Appendix A of the "Development of Tailings and Mine Waste Source Terms for the Proposed Yeelirrie Mine").

6.3 WMC's Tailings Characterisation

A review of WMC's documents dating from 1974 to 1982 was completed to obtain pre-existing geotechnical and tailings data. Among these, the most significant was the geotechnical site investigations and tailings studies completed by Golder Associates for WMC.

Golder (1982) investigated and characterised the tailings through laboratory testing and studies on an experimental tailings pond and two tanks of tailings at the Kalgoorlie Research Plant. These tailings studies were sufficiently detailed that the results can be confidently used in the designs prepared for this submission. The summarised results, along with the results of testing from the current study, are presented in Section 7.2.1.

6.4 WMC's Yeelirrie trial slots and ore stockpiles

WMC mined the first trial slot at Yeelirrie in 1972. Over the following 31 years, various observations and photographic evidence was collected about the long term stability of the pit slopes (Figure 6.1) as well as the stability (i.e. degree of erosion) of the stockpiled materials extracted from the trial slot (Figure 6.2).

Figure 6.1 Trial slot photographed before closure (2003)

Figure 6.2 Stockpiles before closure (2003)

The previous two figures serve to illustrate:

- the natural regrowth of vegetation amongst and on the stockpiles
- the limited erosion of the stockpiles
- the limited dispersion of eroded material from the stockpile sites.

It is noteworthy that the site was subject to several cyclone related rainfall events during the period that the stockpiles were maintained.

The limited erosion and dispersion of the stockpiled material is further illustrated by aerial photos presented in Figure 6.3 and Figure 6.4.However, given the proposed Yeelirrie development is a uranium mine, the clearest evidence for the containment of radioactive materials comes from 2010 aerial gamma radiation survey as illustrated in Figure 6.5.

Figure 6.5 shows a clear gamma signature associated with the ore body and the locations of the historic ore stockpiles. Notably there is no material gamma signature on the playa used as an evaporation pond for water extracted during the dewatering of the slots, nor downstream of the stockpile areas.

Figure 6.3 2003 Aerial photo of the Yeelirrie site before rehabilitation

Figure 6.4 2004 Aerial photo of the Yeelirrie site after rehabilitation

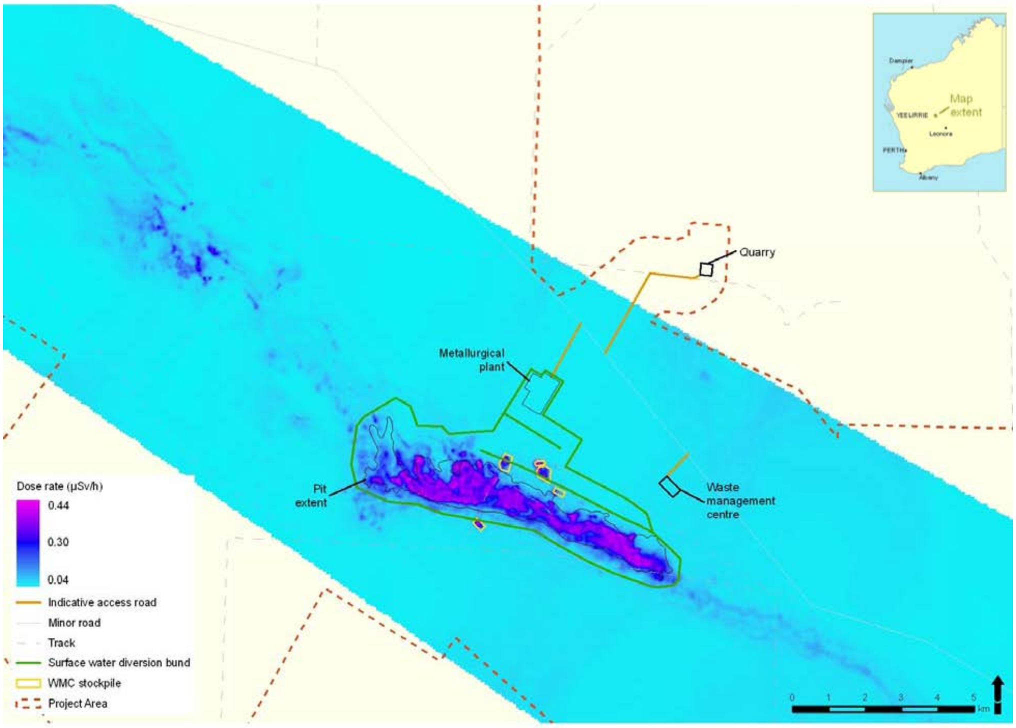


Figure 6.5 2010 Aerial gamma radiation survey

6.5 2004 Site Closure

In 2004, WMC rehabilitated and closed the Yeelirrie site by backfilling the stockpiles of ore into the trial slots.

Using the historical mining records and a recent radiation survey, a closure plan was developed to return the materials in the reverse order to that in which they were excavated (i.e. the most radioactive ores were buried at the bottom of the pit, with the overburden materials being used as covers).

The photo presented in Figure 6.6 is indicative of the degree of revegetation achieved by 2006; some two to three years after rehabilitation works had commenced.

Figure 6.6 Rehabilitated Cover over Trial Slots (approximately 2006)

6.6 Geotechnical Investigations

6.6.1 Field Investigations

Six geotechnical boreholes (drilled for combined geochemistry, hydrogeological and geotechnical sampling) were drilled by BHP up to depths of 30 m below natural surface in August 2009. The locations of the holes relative to the proposed open pit are shown in Figure 6.7. Vane shear, standard penetration testing (SPTs) and soil sampling positions were all recorded.

During drilling for hydrometallurgical samples for resource modelling in 2010, a further five geotechnical holes were drilled by extending selected hydrometallurgical holes below the ore limit to a total depth of 15 m below surface. The locations of these holes were selected to provide coverage of the pit extents. The positions of the boreholes are shown in Figure 6.7. The 2009 series of holes drilled to 30 m deep confirmed the presence of clay beneath the TSF. Resource and hydrogeology drilling has confirmed the presence of clay soils under the entire pit floor (PER, see “Numerical groundwater flow and solute transport model of the Yeelirrie uranium deposit”).

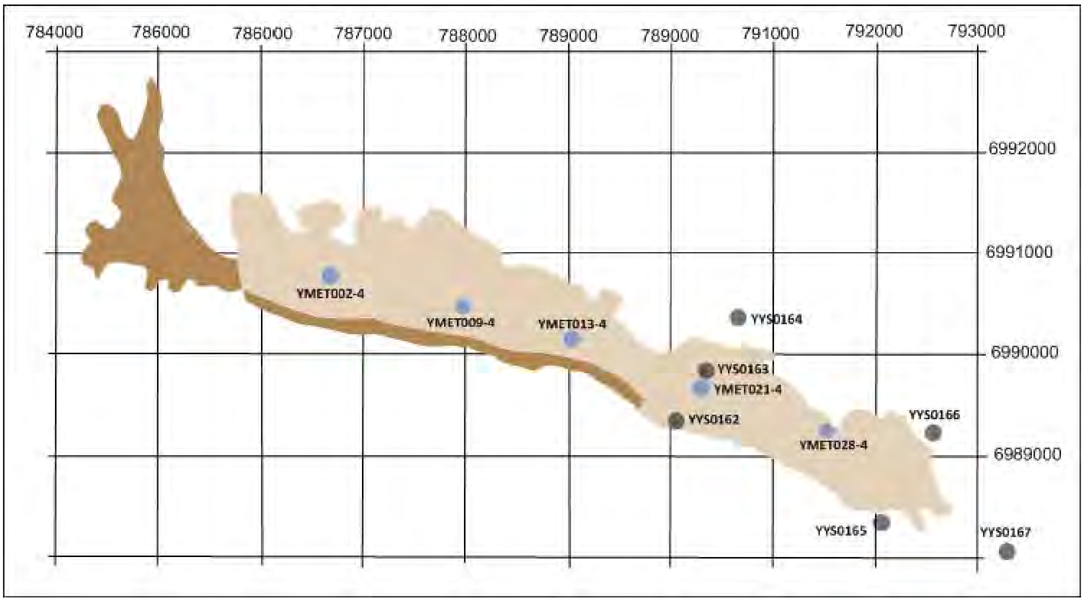


Figure 6.7 Locations of Geotechnical Boreholes (2009, 2010)

6.6.2 Laboratory Testing

Laboratory testing was carried out on five tailings samples prepared during bench scale process testing. The ore-body varies in calcrete and clay content. The higher calcrete ore generally occurs in the western parts of the ore-body, and the higher clay ores in the eastern parts. The test samples were therefore selected and or blended to represent the range of expected ore types that may be encountered during mining and processing; these being:

- YC001 - High calcrete ore
- YC002 - Average blend of ore types from across the ore-body
- YC003 - Average sample across the deposit
- YC004 - High clay-quartz being a higher clay content than the calcrete ores
- YC005 - Very high clay- quartz.

On each tailings sample, particle size distribution, soil classification and cylinder settling testing was carried out. Table 6.1 summarises these results.

The 'liquid limit' (L.L) referred to in Table 6.1 is the moisture content above which the material begins to behave with some plasticity. The solids density at which the liquid limit occurs (shown in the table) provides a measure of the solids density during the deposition cycle when the tailings has sufficient viscosity to remain on a gentle slope, but has not yet been exposed to evaporative drying with consequent behaviour as a "solid".

Table 6.2 lists the hydraulic conductivities of TSF materials.

Laboratory column settling curves for the various composite samples are shown in Figure 6.8. The settling curves provide an indication of the rate of solid/liquid separation. Note however that on a tailings beach, the separation process is far more complex than the settling behaviour in a measuring cylinder. The solids density to which slurry settles on the beach during deposition is significantly higher than the hindered settling in a measuring cylinder.

Figure 6.9 illustrates the grading curves or particle size distribution that indicates that the tailings is appropriately classified as a 'silty sand with some clay'.

Table 6.1 Properties of Yeelirrie tailings

Sample #	Description	Particle Specific Gravity (G)	Linear Shrinkage L.S. (%)	Liquid Limit L.L. (%)	Solids Conc. at L.L. (%)*	Plastic Limit P.L. (%)	Plasticity Index P.I. (%)
YC001	High calcrete	2.73	15.5	65	60	21	44
YC002	Average blend	2.77	13	59	63	21	38
YC003	Average deposit	2.78	14	59	63	21	38
YC004	High Clay-quartz	2.8	13.5	55	65	21	34
YC005	Very high Clay- quartz	2.79	15	57	64	21	36

* Calculated value

Table 6.2 TSF Hydraulic conductivities

Parameter	Hydraulic Conductivity (m/s)		Source
	lateral	vertical	
TSF embankments	1.64×10^{-5}	1.64×10^{-6}	URS (2010)
tailings	1×10^{-8}	1×10^{-9}	URS (2010)
clayey alluvium (underlies TSF)	1.85×10^{-6}	1.85×10^{-7}	URS (2011)
TSF floor (compacted silty clay)		$< 1 \times 10^{-9}$	
calcrete	6.22×10^{-3}	6.22×10^{-3}	URS (2011)
overburden	1.16×10^{-5}	1.16×10^{-6}	URS (2011)

6.6.3 Geochemistry Investigation of the Tailings – 2009/2010

Geochemical modelling of the tailings has been carried out by Cameco and SRK to determine potential porewater concentrations. Cameco's report is presented in the PER (see "Development of Tailings and Mine Waste Source Terms for the Proposed Yeelirrie Mine").

6.6.4 Permeability of the Clayey alluvium underlying the proposed TSF

Hydraulic conductivities determined by laboratory testing

Laboratory triaxial permeability tests were conducted on seven clay samples in 2010. The results are summarised in Figure 6.10.

6.7 Further Trials, Testing and Detailed TSF Design

Sufficient trials and testing have been completed to present a comprehensive description of the design and construction of the proposed TSF.

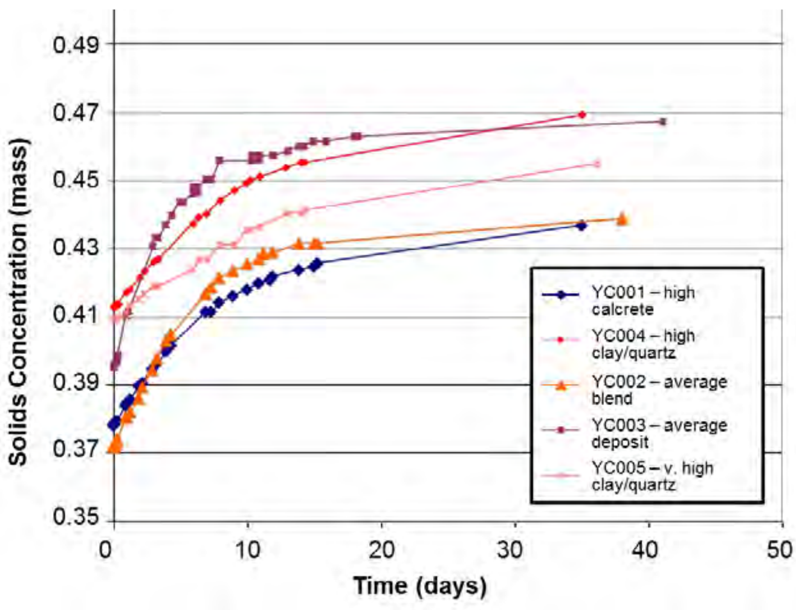


Figure 6.8 Settling curves for Yeelirrie tailings

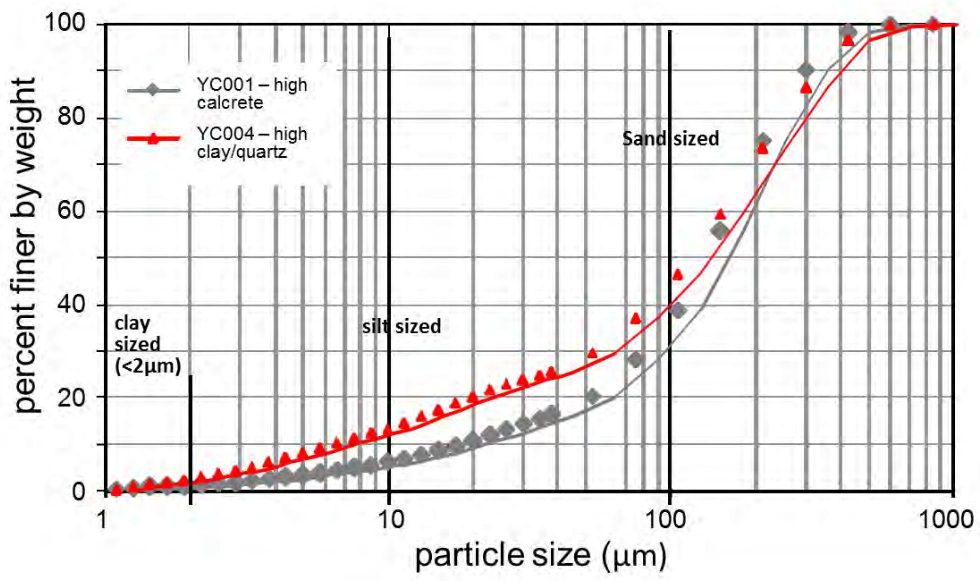


Figure 6.9 Particle size distribution of Yeelirrie tailings

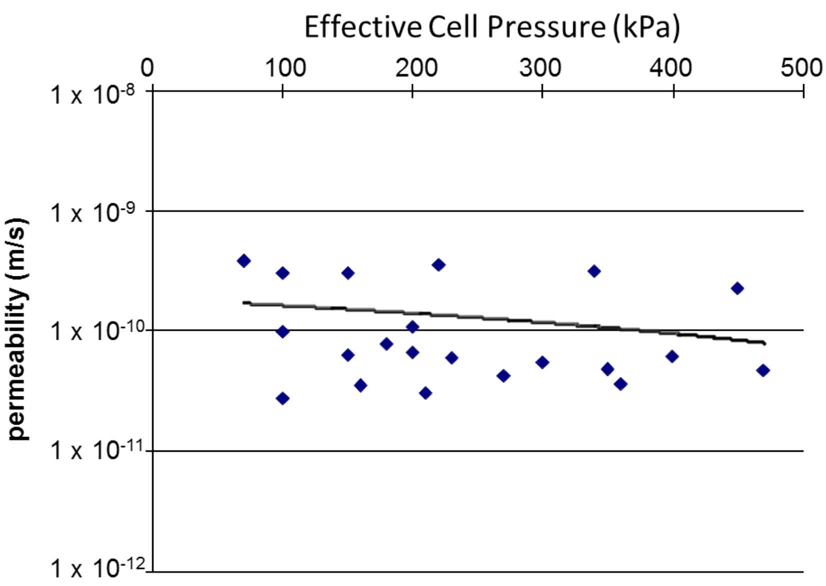


Figure 6.10 Laboratory Permeability of alluvial clays

7 TSF and Tailings Parameters

Based on a combination of both historic and recent investigations, Cameco can define the likely operating parameters for the tailings, as presented in this section.

7.1 TSF Operating Parameters

The operational design parameters are listed in Table 7.1

Table 7.1 TSF operating parameters

Parameter	Value
Annual plant feed (Mtpa)	2.4
TSF Operating Life (approximate years)	19
Discharge slurry solids content (nominal %)	40
Tailings discharge	sub-aerial
Temperature of deposited tailings (°C)	64
Number of Tailings cells (total)	10
Required Tailings cells in use at any given time to meet evaporative requirements	5 (or 3 in the 1st year)
Average size of Pond 1 tailings cells (m^2)	309,031 (5 cells)
Average size of Pond 2 tailings cells (m^2)	339,436 (5 cells)
Plant Operational Uptime	90%
Deposition time (days)	6
Deposition tailings volume - 6 day (m^3)	73,600

7.2 TSF Properties

7.2.1 Geotechnical Properties

Table 7.2 list the physical properties of the tailings – described as a clayey silty sand.

Table 7.2 Physical Properties of the Tailings

Parameter	Value
Tailings discharge density	1.34 t/m^3
Tonnes ore per cubic metre tailings	0.54

Parameter	Value
Deposition tailings volume - 6 day	73,600 m^3
Deposition thickness (per 6 day deposition)	221 mm
Drying time	24 days
As-discharged tailings cell rate-of-rise	2.7 m/yr
Consolidated tailings cell rate-of-rise	1.2 m/yr
Consolidated tailings solids content	70 %
Consolidated tailings density	1.71 t/m^3
Particle specific gravity	2.7
Initial settled solids concentration (by weight)	50-53% (dry density ~0.73-0.81 t/m^3
Beach slope	1%
Coefficient of consolidation	1-16 m^2/yr
Shear strength	0.29 Su/σ_v
Yield shear stress of slurry ~ 40%	20 N/m^2
Plastic viscosity of slurry ~40%	0.014 $N/m^2/s$

7.2.2 Properties of the Tailings Solids

The metallurgical process extracts uranium leaving the other radionuclides in the tailings. As a consequence, approximately 85% of the radioactive material associated with the original ore is left in tailings. The majority of the radionuclides in the ore is from the U-238 decay series. Reagents used for flotation and thickening remain as part of the tailings slurry. The indicative chemical constituents of the tailings are shown in Table 7.3, and the radionuclide concentrations in Table 7.4.

7.2.3 Properties of the Tailings Porewater

Source terms for various constituents of concern (COC) were determined for the proposed Yeelirrie site in-pit tailings storage facility (TSF) at closure (Table 7.5). Development of source terms is described in the PER (see "Development of Tailings and Mine Waste Source Terms for the Proposed Yeelirrie Mine"). Source terms were developed for the following specific tailings constituents, calcium (Ca), chloride (Cl^-), boron (B), arsenic (As), chromium (Cr), copper (Cu), molybdenum (Mo), potassium (K), nickel (Ni), selenium (Se), strontium (Sr), vanadium (V), zinc (Zn), uranium (U), and radium (^{226}Ra) . Source terms were used as input for solute transport modelling found in the PER appendix (see "Numerical groundwater flow and solute transport model of the Yeelirrie uranium deposit").

The radiological concentrations are shown in Table 7.6. With respect to both Table 7.5 and Table 7.6, it is important to note that only uranium goes into solution. All other radionuclides generally remain bound with the tailings solids.

Table 7.3 Constituent Concentrations in the tailings solids

Constituent	Units	Concentration
Aluminium	wt%	3.8
Antimony	ppm	<0.5
Arsenic	ppm	14
Calcium	wt%	10.6
Carbon	wt%	5.6
Copper	ppm	18
Iron	wt%	1.8
Lead	ppm	130
Magnesium	wt%	4.2
Molybdenum	ppm	27
Potassium	ppm	7,480
Selenium	ppm	0.2
Silicon	wt%	20.9
Sodium	ppm	40
Uranium	ppm	150
Vanadium	ppm	260

Table 7.4 Activities of Radionuclides in the Tailings Solids

Radionuclide	Activity (Bq/kg)
Thorium-230	9,540–17,800
Radium-226	9,220–14,300
Lead-210	10,200–15,700
Polonium-210	not analysed
Actinium-227	390–610
Thorium-232	n/a
Radium-228	47–120
Thorium-228	47–79
Potassium-40	290–470

Table 7.5 Recommended Source Terms for the Yeelirrie In-Pit TSF at Closure

Constituent	Units	Cameco Source Term
As	mg/L	4.6
B	mg/L	38.1
Ca	mg/L	5.9
Cl	mg/L	26,000
Cr	mg/L	1.1
Cu	mg/L	0.35
K	mg/L	1,780
Mo	mg/L	2.1
Ni	mg/L	0.05
Se	mg/L	0.49
Sr	mg/L	0.34
U	mg/L	180
V	mg/L	79
Zn	mg/L	0.5
Ra-226	Bq/L	5.0

Table 7.6 Activities of Radionuclides in the Tailings Porewater (excluding U and ^{226}Ra)

Radionuclide	Activity (Bq/L)
Thorium-230	<110–450
Lead-210	<7–37
Polonium-210	n/a
Actinium-227	<2–4.1
Thorium-232	<4
Radium-228	<1
Thorium-228	<0.5–1.5
Potassium-40	42–48

7.3 Hydraulic and Hydrological Design Parameters

In designing an in-pit TSF careful consideration has been given to dewatering the pit both initially and over the operating life of the mine and TSF. Consideration was given to potential inflows from storm water, groundwater and seepage from the TSF.

The proposed storm water management system is described in the PER. This section considers normal operating conditions only, that is, stormwater entering the TSF via a direct rainfall event onto the TSF.

The mine will be dewatered by excavating through the calcrete, which is the primary water conducting material. Approximately 99% of the water flow into the mine occurs through the calcrete and the underlying carbonated clayey sands. A detailed discussion of pit dewatering is presented in the PER (see Numerical groundwater flow and solute transport model of the Yeelirrie uranium deposit”).

It is again noted that the clays beneath the calcrete and the carbonated clayey sands have very low permeability, conducting only minor vertical and horizontal flows (refer to Section 5.2 of this Appendix).

Within the mining area, open drains linked into a sump would be used to keep the water level below the pit floor level for the duration of mining and TSF operations. This would facilitate mining and the construction of the TSF embankments. Water extracted would be used for dust suppression or other on-site requirements.

7.3.1 Design Rainfall

Table 7.7 lists the intensity frequency durations for design rainfall events (refer to the PER, Surface Water). These were obtained using standard Australian Rainfall and Runoff Intensity- Frequency-Duration data (AR&R 1987). From these, the design rainfalls for selected annual recurrence intervals (ARI) are calculated (Table 7.8). An areal reduction factor applicable to large catchments is not applicable to the smaller scale TSF catchment areas.

As noted in DME (WA) 1999, “in general, there is little hydrological data in the remote mining areas of Western Australia that can be used as a basis for the estimation of probable maximum flood levels. In these situations, correlation with records from nearby areas with similar characteristics may be adopted.”

The 1,000 year ARI 72 hour has been used as the design event for the preliminary freeboard analyses.

Table 7.7 Intensity-frequency-durations for design rainfall events

ARI	Rainfall					
	Dur					
	1	6	1	2	4	72
	m	mm/	m	mm	m	mm/h
1	1	3	2	1.	0	0.6
2	1	4	2	1.	1	0.8
5	2	7	4	2.	1	1.2
10	2	8	5	3.	2	1.5
20	3	1	7	4.	2	1.9
50	3	1	9	5.	3	2.5
100	4	1	10	6.	4	3.0
1,00	5	2	13	9.	5	3.8

Table 7.8 Design rainfall for selected ARI

Storm Duration (Hours)	Design Rainfall for Selected ARIs (mm)				
	1-Years	5-Years	20-Years	100-Years	1,000-Years
1	12.5	2	32.1	44.4.0	55.0
6	21	42	64.2	95.4	120.0
12	25.2	54	84.0	127.2	159.6
24	31.2	67	105.	160.8	216.0
48	38.4	81	129.	196.8	259.2
72	43.2	86	136.	216	273.6

7.3.2 TSF Freeboard

The purpose of freeboard is to provide a safety margin over and above all the estimated inflows from extreme natural events and operational situations, so that the risk of overtopping a TSF cell thus leading to embankment erosion and ultimate failure, is reduced to a generally accepted level. The freeboard must be sufficient to store the maximum predicted event (or combination of events) that may occur during the life of the facility, including the worst case situation that also assumes the TSF decant is not operational.

The maintenance of an adequate freeboard is also important when the deposited tailings reach the embankment crest level. The freeboard should be sufficient to contain unforeseen increases in the level and movement of water in the facility.

Freeboard requirements are specified in the DME Guidelines (DME (WA) 1999) and in the ANCOLD guidelines (ANCOLD 2012).

Cameco is committed to designing and operating the TSF such that freeboard requirements are always meet.

DME (WA) 1999

For the Yeelirrie TSF design, the minimum freeboards required by DME (WA) 1999 are:

- **Case1** - pond located away from any perimeter embankment
  Total Freeboard = 500 mm with a sub-minimum of 300 mm Operational Freeboard
- **Case 2** – pond located adjacent to perimeter embankment (no upstream catchment)
  Total freeboard = operational freeboard = 500 mm.

The freeboard is the available height remaining between the crest of the perimeter embankment and the normal operating pond level plus the increase in level caused by a 1:1,000 year 72-hour duration rainfall event falling on the TSF.

ANCOLD (2012)

The ANCOLD guideline categories are similar to the DME (WA) categories, and the Yeelirrie TSFs are rated “high” hazard category dams, because the contamination of stock water resources would be probable if an uncontrolled discharge of tailings and/or tailings water were to occur.

The ANCOLD Guidelines on Tailings Dam Design, Construction and Operation specify design freeboard requirements for high, significant and low category operating

Table 7.9 Design freeboard - operating dams (ANCOLD 2012)

Hazard Category		Spillway/Freeboard Requirements	Additional Freeboard
High		PMF on highest pond level in normal	None
	or	worst wet season on record less water returned to plant, plus 1 in 100 AEP storm plus waves	0.5m
Significant		1 in 1,000 AEP storm on highest pond level in normal year	0.3m
	or	worst wet season on record, less water returned to plant plus waves	0.3m
Low		1 in 100 AEP storm on highest pond level in normal year	0.3m
	or	worst wet season on record, less water returned to plant plus waves	0.2m

Table 7.10 Design freeboard – at closure (ANCOLD 2012)

Hazard Category		Spillway/Freeboard Requirement	Additional Freeboard
High		PMF on highest pond in normal year	None
	or	worst wet season on record plus 1 in 1000 AEP storm plus waves	0.2m
Significant		1 in 10,000 AEP storm on highest pond level in normal year	0.2m
	or	worst wet season on record plus waves	0.2m
Low		1 in 1,000 AEP storm on highest pond level in normal year	0.2m
	or	worst wet season on record	0.2m

Table 7.11 Acceptable factors of safety (ANCOLD 2012)

Loading Condition	**Recommended Minimum for Tailings Dams**	**Shear strength to be used for evaluation**
Steady seepage at high pool	1.5	Effective or total stress
Rapid drawdown from pool	1.2	Total stress, or effective
Earthquake	1.1 for pseudo-static analysis	Total stress or post liquefaction strength
Construction conditions, either slope	1.3 or 1.1	Effective stress or total stress

Table 7.12 Acceptable factors of safety (ANCOLD 2012)

Loading Condition	**Recommended Minimum for Tailings Dams**	**Shear strength to be used for evaluation**
Long-term drained	1.5	Effective Strength
Short-term undrained (potential loss of containment)	1.5	Consolidated undrained Strength
Short-term undrained (no potential loss of containment)	1.3	Consolidated undrained Strength
Pseudo Static	If FOS <1.0 deformation analysis is required	Refer to ANCOLD Guidelines on Earthquake Design
Post-seismic	1.1	Post Liquefaction Residual Strength

dams as in Table 7.9 and for closure as in Table 7.10. The ANCOLD guideline categories are similar to the DME (WA) categories, and therefore the Yeelirrie TSFs would be rated in the 'high' hazard category.

Cameco will design and construct the TSF to meet the high hazard category operating requirements. Additional conservatism is inherent in the Cameco design as the dams are below the natural land surface. The freeboard has been checked (Section 8.8) for a 1,000 year AEP storm immediately following a 100 year AEP storm representing the worst wet season on record.

Cameco will design and construct the TSF to satisfy all loading conditions listed.

7.4 Embankment Stability

The acceptable factors of safety for various loading conditions on embankment slopes are listed in Table 7.11 and Table 7.12 (ANCOLD 2012).

7.5 Radiological Considerations

7.5.1 Overview of Radionuclides in tailings

Tailings from the Yeelirrie processing facility would be placed back into pit voids and covered. This disposal method is both safe and secure for uranium mining tailings.

The two uranium decay chains in uranium ore are the ^{238}U decay chain and the ^{235}U chain. Extraction effectively removes the uranium from both of these chains leaving the remaining radionuclides reporting to the tailings. In natural uranium ore, there is only 0.3% ^{235}U compared to ^{238}U, therefore the dominant radionuclides in the tailings are from the ^{238}U decay chain. The long lived radionuclides are ^{230}Th, ^{226}Ra, ^{210}Po and ^{210}Pb. Radon (^{222}Rn), an inert gas, is produced from the decay of ^{226}Ra. In the ^{235}U decay chain, the long-lived radionuclides are ^{231}Pa and ^{227}Ac.

For an average uranium ore grade of 800ppm, there is approximately 10 Bq/g of each of the ^{238}U radionuclides and 0.03 Bq/g of each of the ^{235}U radionuclides. The concentration of radionuclides in the tailings (excluding uranium) would generally be proportional to the concentration in the ore (that is, the uranium ore grade).

The processing of the Yeelirrie ore, selectively extracts uranium, leaving other materials in the tailings. The testwork shows that the extraction process is almost 95% efficient for uranium, with other metals, particularly the radionuclides not being affected by the leaching process. The other metals remain almost exclusively within the tailings solids.

Following extraction of uranium from the ore the tailings will contain almost 85% of the radioactivity of the original ore.

7.5.2 Source of Radiation from the TSF

The primary sources of radiation associated with the operation of the TSF are discussed below.

Gamma radiation

Gamma radiation levels from the tailings would be consistent with the equivalent amount of ore. This is because the main gamma emitting radionuclide in uranium ore is ^{226}Ra and this radionuclide remains with the tailings. When the tailings have been disposed, and covered, the terrestrial gamma radiation dose rates would be similar to the existing levels.

Radioactive dusts

There is not expected to be dusting of the tailings during operations as the tailings would maintain moisture as they dry and consolidate into a competent mass. Once dried, dusting is expected to be insignificant due to the competency of the tailings. When safe to do so, the tailings would be covered, thereby eliminating sources of tailings dust.

Radon and radon decay product

Radon emanation from the consolidated tailings has conservatively been assumed to be 6 $Bq/m^2/s$. When the tailings are wet, radon emanation is low as the radon is unable to escape from the pore space of the tailings particles. When the tailings dry, there is the potential for increased emanation, if consolidation has not been effective. The estimated emanation has been assumed for the worst-case conditions.

During operations, the radon concentrations in the region of the tailings cells may be elevated due to radon from the exposed tailings.

Radionuclides in seepage

Radionuclides, other than uranium are expected to remain in the solid phase, therefore they are not expected to be in significant quantities within the seepage water leaving the TSF. If seepage does contain other radionuclides, their impact would be minimal as there are no exposure pathways as the seepage moves through the groundwater flow system. Solute transport modelling was performed to track uranium and other constituents of concern in the post-closure environment around Yeelirrie (see

"Numerical groundwater flow and solute transport model of the Yeelirrie uranium deposit").

7.5.3 Controls of radiation

In pit disposal provides an effective means of containing the radioactive tailings with no surface expression. The tailings are effectively being placed from where they came. Once a tailings pond reaches capacity, it would be covered when safe to do so with cover material deemed appropriate and remain permanently secure. Emissions from the tailings are therefore minimised.

Controls include:

- Tailings would be disposed of in mined out pits, minimising the spread of radioactive material
- tailings slurry density at 40% (nominal)
- Disposal in thin layers to aid in drying and consolidation
- Installation of an underdrainage system, if field trials indicate this is necessary
- The geotechnical stability of the design would be assessed using methods described in ANCOLD standards, taking into account the necessary safety factors for high pool (exceeding the minimum freeboard requirements), earthquake loading and normal operation
- During operation tailings would be deposited in rotation among several tailings cells in order to increase evaporation and aid in consolidation
- Recycling of excess tailings liquor to the plant.

8 Specific Design Considerations for the In-pit TSF

This section describes the management of water in the proposed pit, cell and embankment design, tailings deposition and density, pit storage capacity in terms of the TSF, and the tailings cell schedule. It specifically addresses the factors affecting tailings liquor movement into groundwater and the proposed seepage management measures. It describes how flooding will be managed within the TSF. This section also addresses design considerations in respect of TSF closure and rehabilitation.

8.1 Managing Water in the Pit

In designing an in-pit TSF careful consideration has been given to dewatering the pit both initially and over the operating life of the mine and TSF. Consideration was given to potential inflows from stormwater, groundwater and seepage from the TSF.

8.1.1 Surface Water inflows

The proposed stormwater management system for all project infrastructure is described in the PER. This section considers normal operating conditions only, that is, stormwater entering the TSF via a direct rainfall event onto the TSF.

8.1.2 Groundwater Inflows and Dewatering the Pit

Figure 8.1 illustrates schematically how the mine is dewatered by excavating through the calcrete, which is the primary water conducting material. Approximately 99% of the water flow into the mine occurs through the calcrete and the underlying carbonated clayey sands. A detailed discussion of pit dewatering is presented in the PER appendix “Numerical groundwater flow and solute transport model of the Yeelirrie uranium deposit”.

It is again noted that the clays beneath the calcrete and the carbonated clayey sands are very low permeability, conducting only minor vertical and horizontal flows (Table 6.2).

Within the mining area, open drains linked into a sump would be used to keep the water level below the pit floor level for the duration of mining and TSF operations. This would facilitate mining and the construction of the TSF embankments. Water extracted would be used in the process or for dust suppression. The method was proven to be effective during the trial mining operations of the 1970’s.

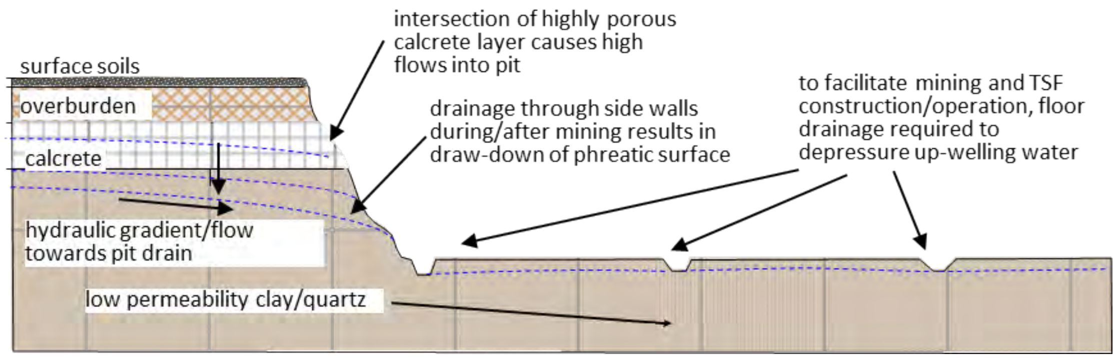


Figure 8.1 Schematic illustration of mine dewatering

8.1.3 Inflows into the pit and to groundwater from TSF seepage

During the operation of each cell, seepage from the base of the cell would be minimised by evaporative drying of each thinly-deposited layer of tailings so that under typical weather conditions there would be no free-water available for seepage from the TSF cell beach.

Whilst a given TSF cell is in operation and tailings are being deposited, there would be a pond around the central decant (the point from which water is collected from the TSF for return to the metallurgical plant). In the event that this pond was permitted to be permanent or relatively large, a 'steady state condition' could develop wherein a mounded phreatic surface or water table would develop. However Cameco is committed to managing the rate of tailings deposition and hence the rate of surface rise, and the size of the decant pond. This along with the relatively low total thickness (height) of the deposited tailings (average final height of tailings will be approximately 7-10 m) and high rate of evaporation would significantly lower the likelihood that such a steady state mounded phreatic surface would establish, and hence makes it improbable that seepage from the TSF would flow into the pit or into the groundwater.

Given the likely low permeability of the tailings ($k_{vertical} \sim 1 \times 10^{-9}$m/s) any water passing through the surface of the consolidated beach would take more than 15 years to move through a 5 m thickness of tailings. So to reiterate, it is highly unlikely that there would be sufficient time during the operating life of a cell (7 to 8 years) for a steady state phreatic surface to be established.

As noted in Section 2, in the proposed TSF, drainage channels would be established in the pit floor to facilitate mining operations in the clay. These would be left in place and possibly used as underdrains as the TSF cells are constructed as a contingency measure for both consolidation and to recover potential seepage from the operational TSF. However, as the tailings and underlying clays are highly impermeable, calculations indicate that the flow to each drain would be very small compared to the evaporation capacity available on the beaches, especially as additional layers of tailings are placed in each TSF cell.

Nevertheless, the drains may prove valuable in controlling seepage out of and into the cells during the deposition phase of the TSF operational cycle, collecting any excess process liquor for recycling back to the plant, and assisting in the drain-down of any excess water remaining in the cell during the first stages of closure. Cameco would review the effectiveness of maintaining the under-drains throughout the cell operation and leading into closure by:

- Incorporating appropriately engineered under-drains (geo-fabric wrapped slotted pipe within drain backfill relatively more permeable than the clay and tailings) in the first series of TSF cells.
- Monitoring the water levels and pore pressures in the base and in the tailings using standpipes and vibrating wire piezometers.
- Monitoring the flow and quality of water collected in the drains.

Based on the information obtained from this monitoring, the drains in the pit floor under the TSF cells would only be used in the cells developed later in project life if the information showed the drains to be of benefit.

8.2 Cell and Embankment design

8.2.1 Layout and geometry

Figure 8.2 illustrates the concept level engineering of the two tailings ponds , each comprised of five tailings cells. The numbering of the cells aligns with the conceptual mine plan, which mines the ore body in ‘blocks’ 1 to 15. As noted previously, Cell 1 is built in the year preceding the commissioning of the processing plant by pre-mining a portion of the first ore block.

The dimensions of the cells vary depending on the geometry of the mining block. The blocks are sub-divided into somewhat regularly shaped cells that facilitate a central decant pond.

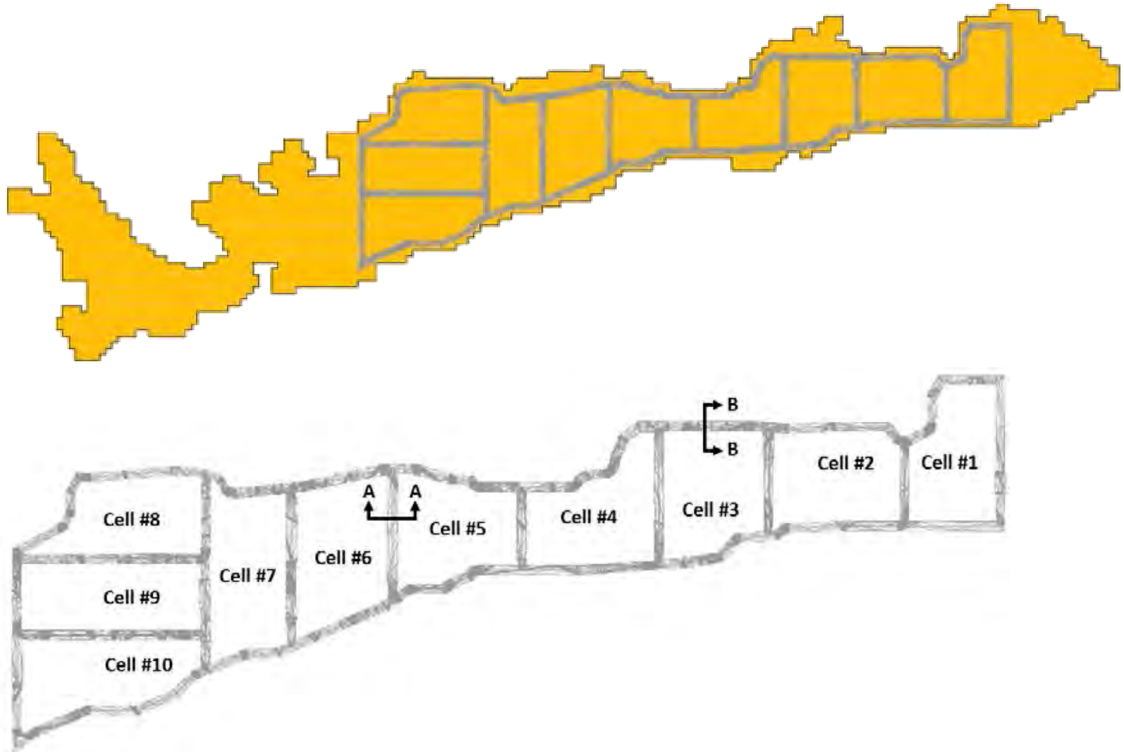


Figure 8.2 Schematic plan showing the tailings cells (top) superimposed over the pit and (b) with tailings cell designations.

Cross-section AA (Figure 8.3 and Figure 8.4) illustrates the geometry and construction detail of interior embankments. Figure 8.3 shows an internal access corridor within the mining area where a TSF is constructed adjacent to an unmined area (the border between cell #5 and cell #6, in this scenario). Figure 8.4 shows a clay embankment between two operational tailings cells or an embankment leading to a central decant area. Cross-section BB (Figure 8.5) shows the geometry and detail of a clay embankment relative to the side pit wall designed to horizontally isolate the tailings from the groundwater.

In general, the embankments would be constructed using silty, sandy clay sourced from within the floor of the cell. This material makes an excellent embankment dam construction material, with a very low permeability when compacted (< 1 x 10^{-9}m/s). Where the TSF embankment walls would not come into contact with groundwater after closure (e.g. the wall dividing Cells 1 and 2), these walls may be constructed using tailings if the tailings are found to be suitable.

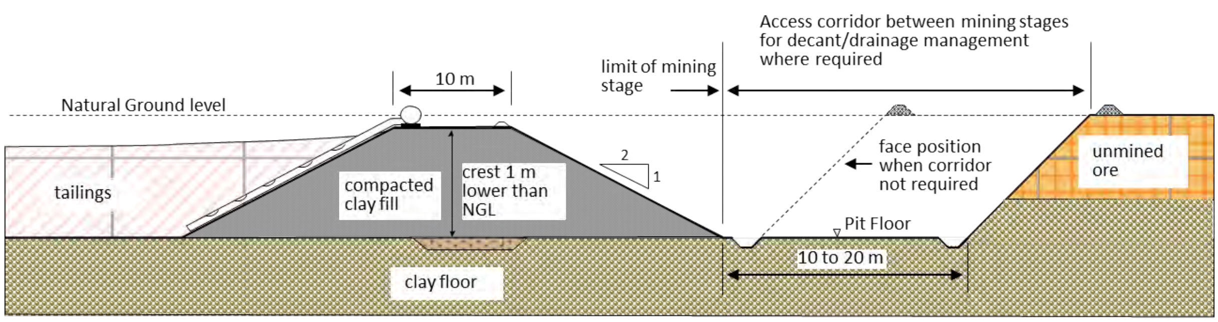


Figure 8.3 Schematic cross section (A-A from Figure 8.2) through an interior embankment between an operational tailings cell and an unmined area with an internal access corridor

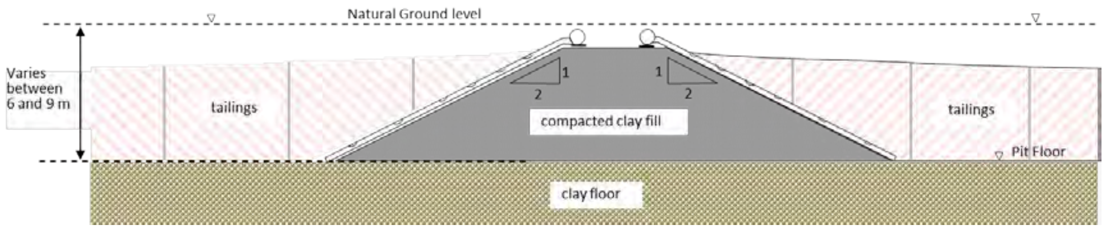


Figure 8.4 Schematic cross section (A-A from Figure 8.2) through an interior embankment between two tailing cells in operation

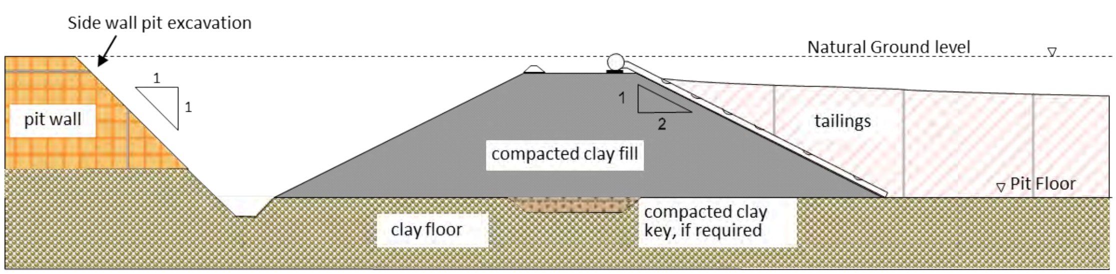


Figure 8.5 Schematic cross section showing a clay embankment position relative to the side wall of the pit.

Geotechnical investigations would be carried out along the location of each embankment to determine the suitability of the floor materials for founding the embankment and for preventing seepage into and out of the cell. Where necessary, floor preparation would be carried out to remove or seal unsuitable material and defects (e.g. joint/faults and cracks), if required. For example, where an embankment is to be constructed on a more permeable carbonated sandy clay material with potentially higher permeability, a clay key/cut-off would extend down to the underlying low-permeability clay (e.g. as shown in fig. 8.5).

8.2.2 Stability analyses

As described in Section 3, the tailings containment embankments would be designed to ANCOLD standards of dam design, to ensure a very low risk of embankment failure under all loading conditions.

Previous stability analyses were conducted on the embankment slope using the program Slope W. The shear strength of the clay materials in the proposed embankments and in the pit floor foundation were found to average c’ = 5 kPa, and $\varphi' = 30^{o}$ based on BHPB data and experience. This is considered to be a conservative estimate of the strength of the silty, sandy clay materials encountered, particularly when compacted. Cameco would perform similar analyses prior to construction of the tailings embankments to confirm the suitability of the material under both dry and saturated conditions.

As described in Section 8.2.1, prior to construction, the position of each embankment would be investigated to determine the properties of the materials in the foundation, and to be used in the wall construction. Stability checks would then be done to confirm that the proposed geometry is suitable for the actual materials found under each cell, and if necessary, the slopes modified to suit.

8.3 Tailings Deposition

The slope of the beach that forms on a given tailings storage system is influenced by a number of factors including the rheology (viscosity) of the slurry, which is in turn dependent on the solids concentration and the type and quantity of clays and other minerals and chemicals contained in the tailings. The particle size distribution and the flow velocity also affect beach slope – similar to sorting and deposition in a natural alluvial channel. The proposed disposal concept is to deposit the tailings sub-aerially directly onto beached (1%) TSF cells located in the mined-out pit at around 40% solids concentration.

As long as the potential seepage issues associated with more water in the tailings slurry are managed effectively (see next section), it is preferable to keep the tailings at a slurry density which facilitates flatter beach slope and more efficient filling of the low height pit voids. The beach angle would be investigated further during pilot processing trials, when small scale beaching (flume) trials would be carried out on the tailings produced, together with other rheological tests to provide a better estimate of likely beach slope.

In the event that the tailings do not behave as predicted and the beach angle is steeper than that required, the slope would be reduced either by diluting the tailings slurry to a lower solids density (by 1 to 2%), or by reducing the number of locations (spigots) from which tailings are released onto the cell and thus increasing the velocity of the tailings released onto the TSF beach, or both. If a beach slope is too flat, then it can be steepened by increasing density (1 to 2%) and depositing from a larger number of spigots (i.e. lowering the flow rate), or by depositing tailings for a shorter duration.

8.3.1 Drying Phase

Deposition would be cyclically rotated among five TSF cells over a 30 day period to achieve an approximate 100 mm increase in depth of consolidated tailings. It is expected that deposition would occur over six days and then be moved to the next TSF cell. During the six day deposition, tailings would be deposited from spigots placed along the perimeter walls onto the beached cell.

8.4 Tailings density and pit storage capacity

The dried tailings density is important in estimating the storage capacity required, in aligning the TSF schedule, and in demonstrating that the pit-void would be big enough to store all the tailings and the overburden backfill.

Geological investigations have shown that the dry density of the ore body is about 1.43 t/m^3. Some bulking would occur, but it is expected that when returned to the pit, the overburden backfill would reach a density of at least 1.4 t/m^3. This is confirmed to some extent by the earlier closure works by WMC in 2004 where the stockpiles were comfortably backfilled into the trial pits.

Tailings drying data collected at the Kalgoorlie Research Plant (KRP), as documented soon after deposition, indicated that the 'weak' tailings reached a dry density of at least 1.2 t/m^3 (Golder 1982). Moisture data collected in 2009 and historical photographs of the KRP TSF closure works showing earthworks equipment on the tailings surface indicating that the density increased well above the 1.2 t/m^3 measured by Golder in the earlier stages of drying in the test tanks (the Golder results were for full depth tailings, not for thin layer deposition as would be used at Yeelirrie). The drying tests during this program also indicated that dry density of the tailings could reach 1.4 t/m^3 (see photographs and figures in Section 6.4).

For the purposes of the concept level design, a dry density of 1.2 t/m^3 has been assumed for tailings. This is considered to be conservative (i.e. the actual density would be higher than 1.2 t/m^3), and the impacts of any density increase above this would be beneficial to the design in all respects.

8.4.1 Pit storage Capacity

The proposed mine pit closure design is to cover the tailings with at least 2m of material. While ore grades do vary, and higher grade and lower grade ores would be stockpiled separately. The mine plan indicates that the overburden stockpiled around mine would be sufficient to cap the tailings with a cover approximately two metres deep.

The sensitivity of the all-of-pit volume balance was tested using a range of waste and tailings densities. The results indicate that a 1 m in 200 m shedding profile (which is very gentle and would not promote erosion) would balance the expected increase in volume from bulking.

8.5 Tailings Cell Schedule

The tailings cell schedule is shown in Table 8.1. At the start of milling, three tailings cells will be prepared for tailings deposition. Calculations indicate that that will provide sufficient tailings space in the first year of operations with somewhat reduced production. Tailings cells 4 and 5 are scheduled to be ready in the latter half of the first year. With the exception of the first year of operation, the mining schedule leads the tailings schedule by at least two years at all times (i.e. there is always sufficient pit voids to store tailings).

Based on the aim of drying the tailings to the extent that no seepage occurs from the beach, the 15 year life of mine tailings schedule has been developed such that sufficient tailings storage area has been provided for an average rate of rise of around 1.2 m/year. Each cell would operate for seven years with slower deposition planned for the first year when the floor is being ‘lined’ with tailings and also in the last year when the final filling occurs and preparations begin for establishing the cover on the tailings surface.

Table 8.1 TSF Operation and Closure Schedule showing the volume of tailings to each cell as a function of year. In this table year 1 coincided with the first year of tailings disposal

	Tailings Cell No.									
	Tailing Pond 1					Tailing Pond 2				
	1	2	3	4*	5*	6	7	8	9	10
year mined	-2	-2	-1	-1	1	1-2	2	3	4	5
cell area (m^2)	229,437	329,628	335,888	335,119	315,084	358,751	358,751	358,751	358,751	358,751
year										
1	236,745	306,962	311,350	117,432	110,411					
2	296,857	426,489	434,589	433,594	407,671					
3	296,857	426,489	434,589	433,594	407,671					
4	296,857	426,489	434,589	433,594	407,671					
5	296,857	426,489	434,589	433,594	407,671					
6	296,857	426,489	434,589	433,594	407,671					
7	296,857	426,489	434,589	433,594	407,671					
8	252,385	362,597	369,483	368,637	346,598	63,309	61,735	54,008	61,081	59,369
9	rehabilitation** cells #1-5					422,592	412,084	360,507	407,720	396,297
10						422,592	412,084	360,507	407,720	396,297
11						422,592	412,084	360,507	407,720	396,297
12						422,592	412,084	360,507	407,720	396,297
13						422,592	412,084	360,507	407,720	396,297
14						422,592	412,084	360,507	407,720	396,297
15						94,843	92,484	80,909	91,505	88,941
16						rehabilitation cells #6-10				
17										
18										
19										

* tailings cells #4 and #5 will come on-line in the latter half of the first year of deposition

** during rehabilitation of cells #1-5 cover trials will likely occur to determine the best cover system to use in the rehabilitation of the tailings cells.

The cell sequencing has been linked to the laboratory density results and the drying model to ensure there is always sufficient drying time and evaporation capacity, if not on a daily basis, then at least on a seasonal and/or annual basis, to achieve the assumed volume target density of 1.2 t/m^3.

At an average rate of rise of 1.2 m/year, the modelling shows that only 74% of the annual evaporative capacity is required to evaporate all beach water freed in consolidating/drying to the average 70% solids concentration (i.e. there is a factor of safety of 1.37 in the evaporative capacity). As discussed in Section 8.6.3, in determining the available evaporation, the seasonal pan evaporation rates have been factored by appropriate pan beach evaporation factors.

If observations in the first years indicate that additional evaporation capacity is required, the mining schedule leads the tailings schedule by two to four years (i.e. there is additional pit void area available for constructing additional cells). The construction of additional cells could be brought forward permitting deposition at an even slower rate of rise to achieve the final state required. Other possible contingencies have already been discussed in other sections of this document including underdrains that could aid in producing negative pore pressures resulting in deep vertical cracking of the clay-rich tailings thereby enhancing evaporation. Removing additional available tailings decant could also aid the rate of evaporative drying from the surface. A 29.5 hectare evaporation pond is planned to add additional contingency for evaporation capacity.

The in-pit solution allows further contingency in that the ‘sequential smaller cell modular approach’ allows the early testing of the design assumptions. If issues are noted in the first years of operation, for example, beach slope, inadequate drying, available storage capacity, the mining of future blocks can be accelerated to provide more deposition area.

8.6 Factors affecting tailings liquor movement into groundwater

The disposal and drying of the tailings and management of water are key to achieving the target tailings dry density (and hence fit all the tailings in the pit) and to minimising seepage and its consequential environmental impacts.

Tailings water management, and in particular the amount of potential seepage, is strongly influenced by how fast the cell is filled (the rate of rise), which in turn is influenced by the:

- tailings settling behaviour (Section 8.6.1)
- tailings drying behaviour (Section 8.6.2)

- available evaporation capacity (Section 8.6.3).

Understanding these behaviours assists in establishing the design requirements (i.e. the area of tailings storage required to manage the tailings and water).

As discussed in previous sections of this report, and specifically Section 8.1.3, the clear expectation is that there would be little or no seepage of tailings water from the TSF to the surrounding groundwater system during their operation life.

When groundwater levels within the pit and TSFs start to recover in the initial post-closure period, the hydraulic gradients in the groundwater are toward, rather than away from the TSF cells. This would prevent any migration of solutes from the TSF to the external environment during the drawdown recovery period.

8.6.1 Tailings settling behaviour and decant

The quantity of water that reports to any given decant pond in the proposed TSF can be estimated from the difference in the solids density at deposition, and the solids density after about 24 to 48 hours, when free water stops flowing over the surface of the beach.

The settling tests indicate that the immediate change in solids density for settling in a measuring cylinder is around 6 to 7%. Comparisons between cylinder and beach differences from other tailings dams has revealed that the change on an actual beach is larger than the cylinder test, because the beach is a dynamic system, compared to the static system and hindered settling in the measuring cylinder.

For the purpose of the PER design water balance analyses, the immediate average settled density on the beach has been assumed to increase from the 40% deposition solids density to 50% solids. This is considered to be a conservative assumption and is not critical to the design. The only aspect of the water balance that this assumption affects is the quantity of water returned to the process plant.

8.6.2 Tailings drying behaviour

During March 2010, BHPB conducted drying tests on tailings samples to investigate:

- The drying behaviour of the tailings, and in particular the ‘air entry point’, which indicates the moisture content at which the tailings begin to de-saturate. This is important for determining the moisture content at which the tailings should be kept to minimise radon emanation. Trials at Ranger showed that the radon emanation from tailings kept below the air entry point were similar to submerged tailings.

- The dried surface properties of the tailings. It is important to demonstrate that through evaporative drying, the concentration of salt within the near surface material would aid in the formation of a durable non-dusting crust.

Figure 8.6 illustrates the drying curve (% water remaining versus drying time) for two samples each of tailings derived from high clay ore, high calcrete ore, and samples of tailings process water. This demonstrates that during the first 24 to 48 hours, tailings dry at about the same rate as the free water. Thereafter, tailings dry at a slower rate, for a day or two, as the suction forces associated with partial saturation begin to act on the pore water.

The curve also illustrates the effect of salinity on the free water evaporation rate, which reduces as the salt concentration increases. At higher salinities, the evaporation from the residual brine almost stops completely.

The potential impacts of salinity on the drying and the mass balance would be investigated further during the post-PER submission testing program, but this effect is not material to the design considerations at this stage because the design is based on very thin (100 mm) layers. There would be no impediment to drying the full depth of these layers (rainfall events aside) over a period of 20 to 30 days, irrespective of the salt content.

Figure 8.7 illustrates the drying curve in terms of solids density versus drying time. On this curve, the air-entry point is clearly defined. At solids densities below the air entry point (about 68 to 70% solids), the tailings would be fully saturated as they consolidate because of drying evaporation (i.e. the voids between solid particles are still all filled with water).

At solids densities above air-entry point, the voids begin to become partly unsaturated (consolidation slows and air enters the voids). In a partly saturated state, the pore water pressure becomes negative (suction) which results in a noticeable reduction in the permeability of the material, and in the seepage. For seepage to occur, the pressure head must be greater than the suction force.

This is an important principle in the control of seepage from the Yeelirrie TSF, where seepage from the tailings would be controlled by drying out the tailings to moisture contents less than the air-entry point – but not so far that radon emanation becomes elevated. This is done by providing sufficient surface area such that the annual evaporation, after accounting for salinity effects and rain infiltration, exceeds the water remaining in the beached tailings.

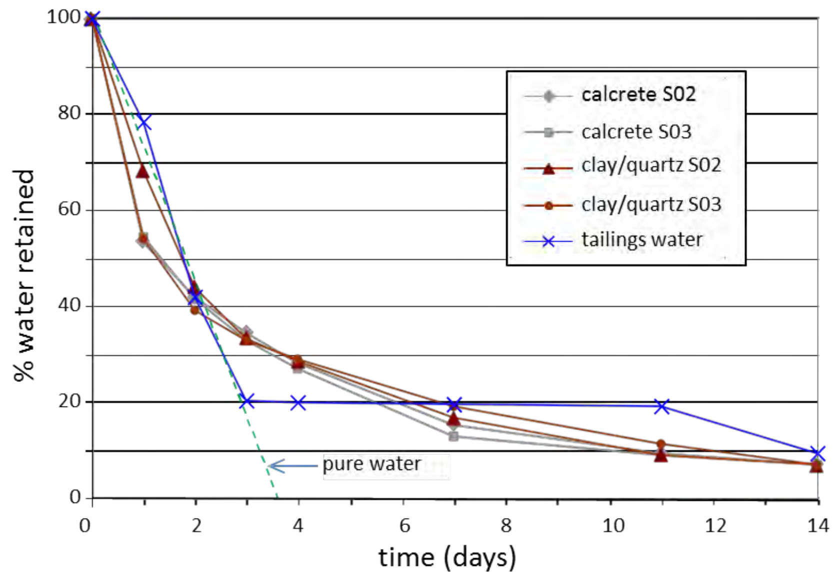


Figure 8.6 Tailings drying curve showing the percent water retained versus drying time

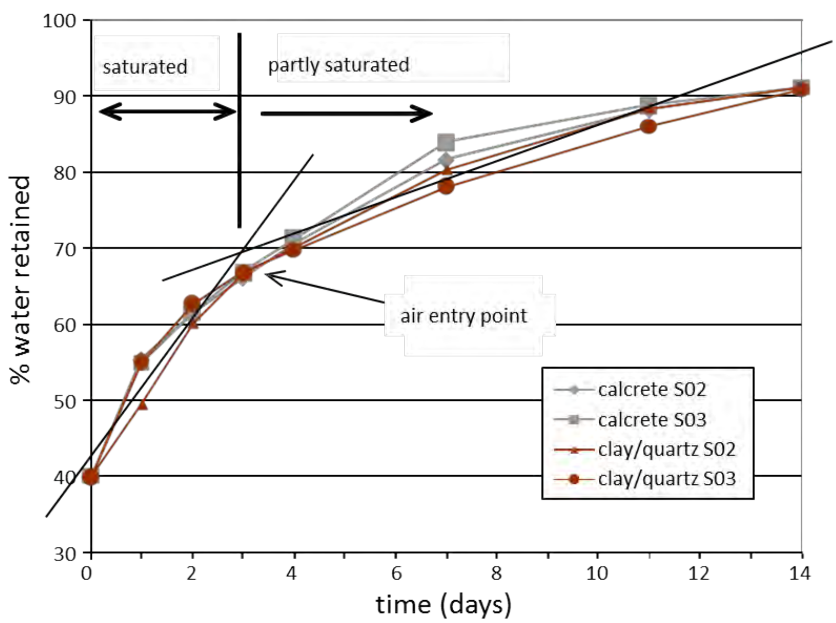


Figure 8.7 Tailings drying curve – percent solids vs. drying time

Day 1 - 40% Solids Density

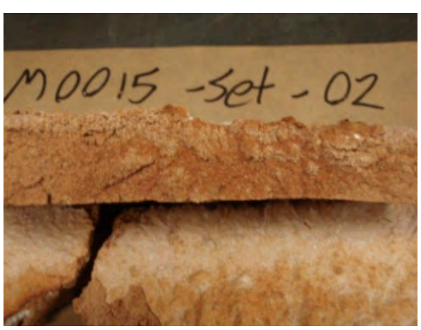
Day 2

Day 4

Day 11

Day 12 – Removed from tin

Surface brushed



Section view of hardened tailings

Figure 8.8 Photographs of progressive oven drying of Yeelirrie tailings at 450^{o} C

Figure 8.8 shows a series of photographs illustrating the progressive drying and crusting of the tailings. Drying to the target density at the air entry point was complete after approximately three days.

The actual drying rate in the field would start at a higher (settled) density, and may be initially be faster (depending on humidity) because of the tailings temperature (~ 60^{o}C) at deposition. However, once the tailings have cooled down on the beach, the drying rate would be slower than the rate in Figure 8.7 because the average temperature is less, drying can only occur from the surface and evaporation slows at night. The removal of supernatant would also assist in reducing the effects of salt concentration on the evaporation rate.

The post PER submission testing program would attempt to mimic the beach drying, by allowing the tailings to settle, removing the supernatant water, and then commencing the drying test. The layer thickness would match the proposed design layer thickness. This would provide more accurate drying data for the proposed design and drying time.

The drying tests also demonstrated that under strong drying conditions (the temperature at Yeelirrie frequently exceeds 40^{o}C in summer) the tailings reach dry densities exceed 1.4 t/m^3. Notwithstanding the limited information, there is strong confidence that the 70% target solids concentration is achievable within the 30 day beach rotation cycle, particularly when considered on an annual basis.

8.6.3 Available evaporation capacity

Once the decant water has been removed, the water balance is essentially controlled by the amount of evaporation. At Yeelirrie, the beach drying process is analogous to an evaporation pond built on a clay base, designed to evaporate all water on an annual basis - except that there are also tailings solids present.

The amount of evaporation also controls seepage from the beach. Blight (2010) notes there is a misconception that water that infiltrates into the ground (or tailings) would all migrate down into the ground below and further. This is incorrect for it has been shown that summer surface evaporation/drying is able to draw the water from depths of 5 metres below the surface.

Standard practice in estimating evaporation is to firstly convert the tank or pan evaporation to a lake evaporation using a pan factor of (0.85). A brine factor is also used to account for the reduced evaporation of the saline liquor (0.8). In combination the effective evaporation rate is factored at 0.68 from the pan rate.

The amount of evaporation required to minimise seepage from the beach is estimated by modelling the drying process, which occurs in three stages:

- During deposition (six days) the freshly deposited slurry on the beach is semi-liquid and there is free water on the surface of the beach which evaporates at an accelerated rate (0.7 x pan x tailings temperature multiplier) because the tailings temperature (65°C) is significantly higher than ambient throughout the year.

- During the second stage (about two to three days after deposition stops) the tailings begin to consolidate to a plastic state, with excess pore water bleeding upwards onto the beach surface. During this period the full available evaporation rate (0.7 x pan) is again used as the surface bleed is freely evaporable.

- Over the third stage - the drying stage - an annualised average 0.5 x pan evaporation rate is used. For a drying beach, Blight (2010) notes that the actual solar evaporation capacity measured for evaporation on landfills is actually more around 0.4. Data from other sites in Australia indicate a beach drying factor of ~ 0.5 is realistic given that there is more water in the tailings beach available to be evaporated than in the landfill case. Hence a beach drying factor of 0.5 was used for the drying beach at Yeelirrie.

During winter, the tailings would remain moist, and water not drawn off by evaporation would be available for seepage. However, if the base through which this seepage needs to flow is very impermeable (as is the case at Yeelirrie where the clay base has permeability of the order of $1x10^{-9}$m/s), and the height of material through which the water must be extracted is low (average 6 m at Yeelirrie) this water can be extracted by evaporation during the summer months when there is excess evaporation capacity available after drying the newly deposited layers.

During summer, if a sufficient drying area is provided, there would be excess available evaporation capacity - sufficient to dry out the available "summer" free water as well as the excess held over from winter.

The degree to which the tailings dry out also depends on the thickness of the deposited layer. In addition, the formation of a low permeability salt crust on the surface can also reduce the evaporation rate, thus the thinner the layer the more effective the drying. Tailings drying may also be complicated by the presence of clays and their interaction with sodium.

For the drying analysis, the target maximum solids density during the drying stage has been assumed to be around 68% in winter and 72% in summer for an annual average of 70%. This corresponds with the air entry point; the target moisture content at which tailings needs to be maintained to minimise radon emanation. At rates of rise above 1.6 m/year, there is insufficient evaporative capacity to consume all the excess water resulting in seepage from the floor of the beach.

The rate of rise also impacts the amount of water returned to the decant pond in that:

- Water is consumed in wetting up a dry beach.
- At high rates of rise, the deposition cycle remains on a section of beach for a longer period, the beach remains flatter, and tailings do not reach the same immediate settled density, with more water remaining on the beach.

Hence the lower the rate of rise, the drier the beach and the more water lost to beach wetting up when a deposition cycle is started. From this analysis, the estimated average annual water return is around 15%, which would vary seasonally – from between about 10% in summer to about 20% in winter.

8.6.4 Seepage Minimisation

Seepage of tailings water out of the TSF into the surrounding soils and rock could occur from the beach and from below decant ponds. As already demonstrated, under the normal operating conditions, if a slow enough rate of rise is used, all the excess water available for seepage from the beach would be evaporated, in which case there would be little if any seepage.

As discussed in Section 8.1.3, some seepage would also occur from below the decant pond, but each in-pit TSF would only operate for a period of seven to eight years, and would have a maximum head above the clay base around 4 to 6 metres, resulting in a relatively small quantity of seepage, if any.

8.6.5 TSF Seepage Management

Control measures for minimising seepage include:

- During preparation of each tailings cell geotechnical investigations would be carried out to determine the suitability of the floor materials for seepage control as well as to check for defects (cracks/faults/joints). The position of each embankment would also be inspected.

- The decant pond would be located well away from the side walls to eliminate any connection between a source of free water and any wall or floor defects.

- During mining/milling the pit area will be actively dewatered. The water quality from the dewatering wells will be regularly monitored and tested. Deviations from an accepted baseline water quality will trigger mitigation actions.

- Thin layer deposition and drying of tailings. The tailings (permeability < $1x10^{-9}m/s$) increase the effective depth of the underlying permanent base liner.

- Internal under-drains would be used, at least in the first cells, and in later cells if found to be effective, to prevent upwelling of groundwater into the TSF during operation, and seepage out of the cells during operation and in the lead up to closure. Monitoring equipment will be installed to better understand the pore pressures in the tailings and the in-situ tailings porewater quality (e.g. vibrating wire piezometers, stand pipes).

The underlying 40 to 60 metres of clay acts as an effective liner, and hence, together with the proposed dry beach operating method to minimise seepage, and ‘shedding store and release closure’ cover designed to minimise infiltration after closure, a geosynthetic liner is not needed on the TSF base.

To summarise, the proposed design controls would limit the volume and rate of release of tailings porewater by:

- drying the tailings during the deposition cycle hence limiting mobility of the pore solutes
- consolidating the tailings hence ensuring very low permeability and leachate flux
- covering the tailings as soon as possible after filling a cell to prevent infiltration that would mobilise potential contaminants in leachate
- providing suitable drainage within and around the TSF to prevent groundwater from re- entering the stored tailings
- including design elements to facilitate the monitoring the groundwater levels and quality and providing contingency measures to abstract any polluted groundwater before a harmful impact occurs

8.7 Dusting from the TSF Beaches

At the end of the drying tests described in Section 8.6.2, the samples were broken to observe the drying profile, and the surfaces brushed to determine the approximate loss to dust if the tailings were to dry to this extent. The brushing resulted in approximately 1.7% loss of dry mass, indicating that dusting from the tailings would be negligible, particularly when the surface moisture is controlled at around 70% solids concentration. In general hydrometallurgical tailings from saline water processing are not prone to dusting due to the salt crusting at the evaporation surface.

8.8 Flood Management

8.8.1 Surface water diversion

Surface runoff from flood events within the Yeelirrie catchment would be diverted around the mining area using the proposed surface water diversion bund. Stormwater management systems including diversion channels and retention ponds would be used within the perimeter bund (see the PER, Surface Water, for details).

8.8.2 Freeboard – precipitation directly on the TSF

During operation of any cell, a basin is formed by the beach. The minimum available freeboard occurs during the last year of operation of a cell, and in the year following its final filling, when the tailings reach their maximum height. The available freeboard is the height difference between the top of the pond and the crest of the embankment. For a 500 m square cell, the available height difference is 2.8 m. This includes the required beach freeboard of 300 mm.

Because the in-pit TSF cells are initially built to full height, additional freeboard is provided by any unused tailings storage capacity i.e. the difference in height between the top of the beach and the maximum level of the beach (300 mm below the crest for beach freeboard).

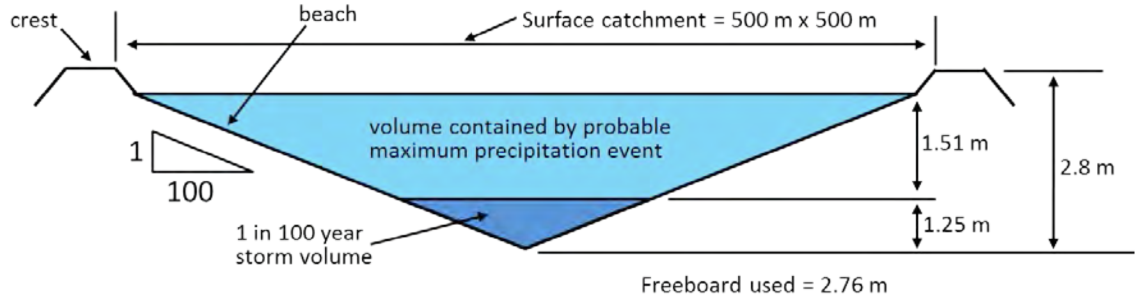


Figure 8.9 Schematic illustration of available beach freeboard

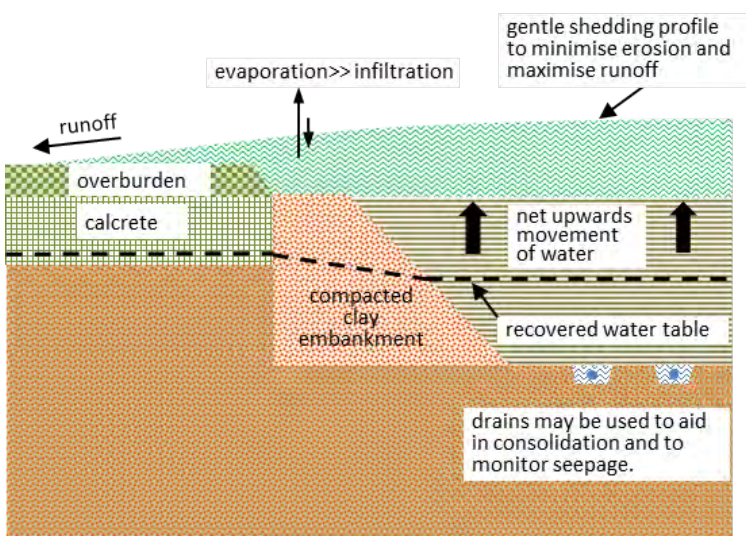


Figure 8.10 Schematic illustration of TSF closure design

The most severe storm events are likely to occur in summer – associated with cyclone activity – and hence the maximum level of the central decant pond would be low. The freeboard available within the TSF bowl is demonstrated (refer to Figure 8.9) by assuming that a 72 hour 1,000 year ARI event (274 mm) occurs immediately following a 72 hour 100 year ARI storm event (220 mm).

Figure 8.9 illustrates that in this very unlikely situation, the remaining freeboard of 0.7 m satisfies DME Guideline and ANCOLD freeboard requirements requiring 0.5 m plus wave freeboard (wave runup is expected to be small as the cells would be below ground level and protected from wind). Depending on the actual beach slope that is achieved (e.g. if the beach slope was less than 1%), then the capacity in the basin would also decrease. If it is found the actual beach slope would not provide the required freeboard in the last year of filing, the required storm capacity would be achieved (if necessary) by lowering the crest level over a portion of one side of the affected cell (a spillway width, with suitable erosion protection) so that excess storm water can cascade into the adjacent partially filled TSF. Thus in the highly improbable event of a storm event that exceeds the final year freeboard, all water overtopping an individual filled TSF would still be captured in the TSF system, and would not be released into the pit void.

Additional contingency capacity is provided by the fact that the mining schedule leads the TSF schedule by a number of years. Hence there would always be partially filled TSFs, with water retaining capacity (the embankments are designed as if they are dam walls), to accommodate the worst possible scenario without releasing contaminated surface water into the pit void.

8.9 TSF Closure and Rehabilitation

As addressed in the PER, Mine Closure, closure and rehabilitation design criteria would be defined, and performance objectives decided upon with the responsible decision making authorities.

Notwithstanding these arrangements, it is proposed that the key design features and principles include:

- Covering the tailings with at least 2 m of benign overburden designed to limit radioactive emissions to levels equivalent to those found prior to mining activity, and to limit the depth of infiltration of rainfall into the cover, and effectively prevent surface water from driving the migration of contaminants from the buried TSF into the surrounding groundwater.

- Contour the cover to create a water shedding profile where incident rainfall is transported laterally to the cell perimeters and shed into the surrounding natural environment without significant erosion or entrainment of the cover.

- Provide a cover that can be revegetated, which may require the inclusion of a capillary break layer over the tailings mass.

- Designing the post-closure landform so that a depositional environment is created whereby natural erosion products from the breakaways build up over the tailings mass slowly over a geological timeframe.

The earthworks associated with the proposed pit (and hence TSF) closure is shown schematically in Figure 8.10.

8.9.1 Cover Modelling

Previously, infiltration and evaporation modelling of the proposed cover was carried out by BHP using Vadose/W (Geo-Slope, 2007). VadoseW allows the modelling of the vadose zone, which is the unsaturated zone between the ground surface and the phreatic surface or saturated zone. The objective of this modelling was to demonstrate the concept of net zero infiltration into the cover and through the vadose zone over an extended period of time.

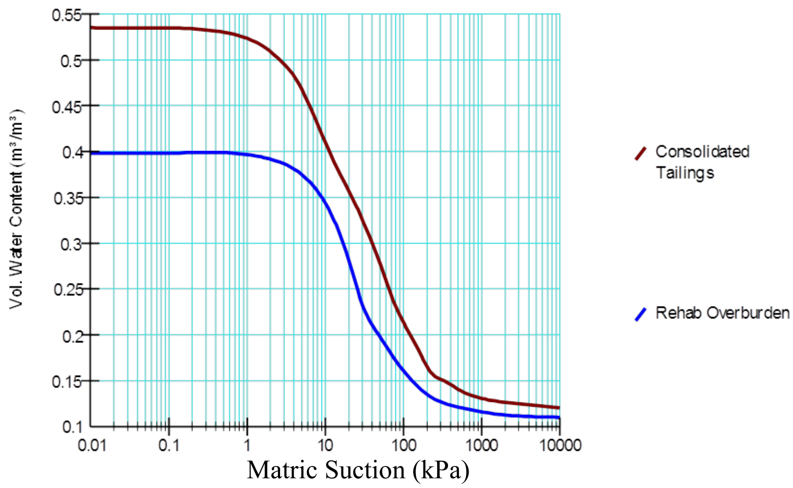


Figure 8.11 Estimated volumetric water content vs matric suction curves for tailings and overburden

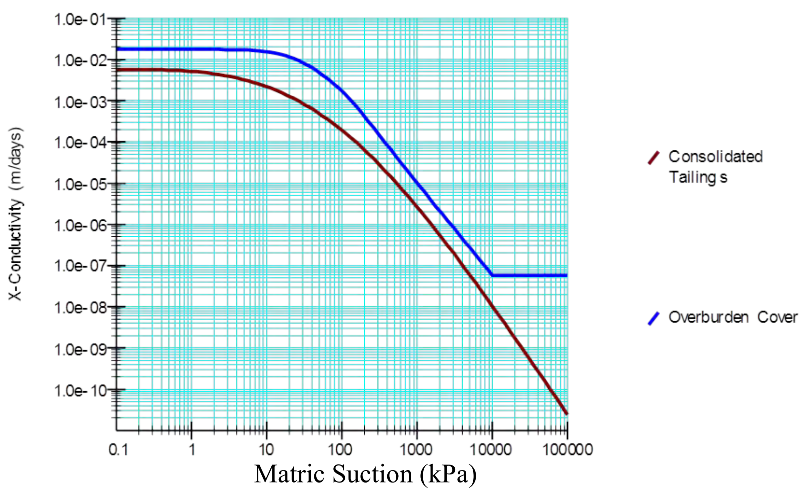


Figure 8.12 Matrix suction curves for tailings and overburden

Figures 8.11 and 8.12 illustrate some of the results of that modelling exercise carried out by BHP. In order to model what might be considered a worst-case scenario, the cover was subjected to a modelling scenario involving:

- Two years of daily meteorological data extracted from SILO covering the period of 1995 (i.e. including Cyclone Bobby).

- At the end of the 2nd year, a 1 in 100 year 72-hour storm has been simulated – 3 days of 72 mm rainfall.

- The outcome of the 1 in 100 year storm has been modelled as a flood with a constant level 1 meter above ground surface for a period of 3 weeks.

- Once the flood level has receded, the cover is then modelled for a further year, again using 1995 data.

The cumulative precipitation is shown in Figure 8.13. At the end of the three-year cycle, the total precipitation is 1,376 mm compared with the three-year annual average of 714 mm. The cumulative water balance for the modelled area is shown in Figure 8.14.

The modelling clearly illustrates the dominance of evaporation over rainfall in the Yeelirrie context, confirming that over the very long term, there would be an annual cumulative water deficit in the covered tailings - noting that the first year reflects the start up on a saturated surface which would not be the case in reality.

The negative water balance reflects that there would be a net upwards movement of pore water from the tailings, with the net effect that if there is insufficient water feeding into the tailings from the groundwater (which is likely to be the case), then the phreatic surface in the tailings (i.e. the level to which the tailings is re-saturated after closure) would be lower than the level of the groundwater outside the TSF.

This means that the contaminants within the tailings pore fluid are permanently being concentrated upwards into a concentration zone above the phreatic surface, as opposed to being driven downwards into the clay underlying the tailings. Hence there will be a net zero flux of contaminated seepage across the base of the tailings after closure.

Cameco has explored various infiltration and recharge scenarios to explore the sensitivity of solute transport to the recharge value (see "Numerical groundwater flow and solute transport model of the Yeelirrie uranium deposit"). Uncertainty around the correct net infiltration number fuels the contradictory predictions from previous URS and BHP studies concerning solute seepage. Given the contradictory conclusions from

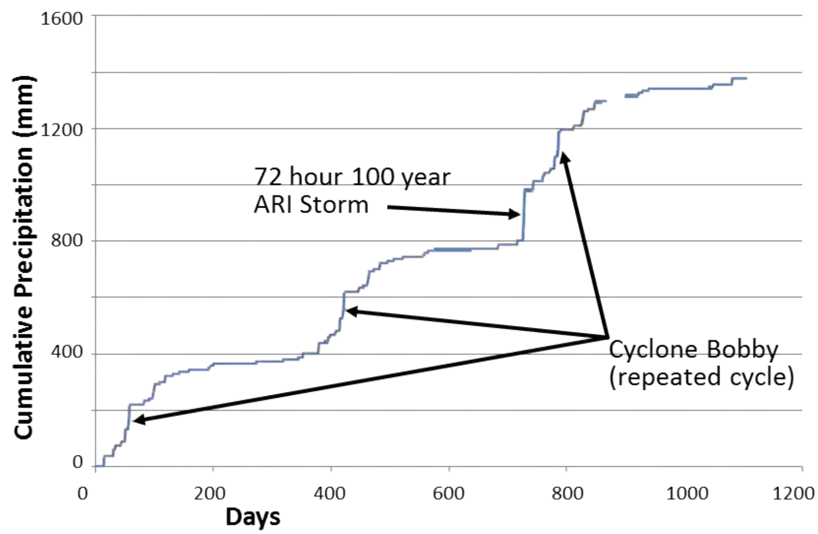


Figure 8.13 Cumulative precipitation over model period (3 consecutive 1995's)

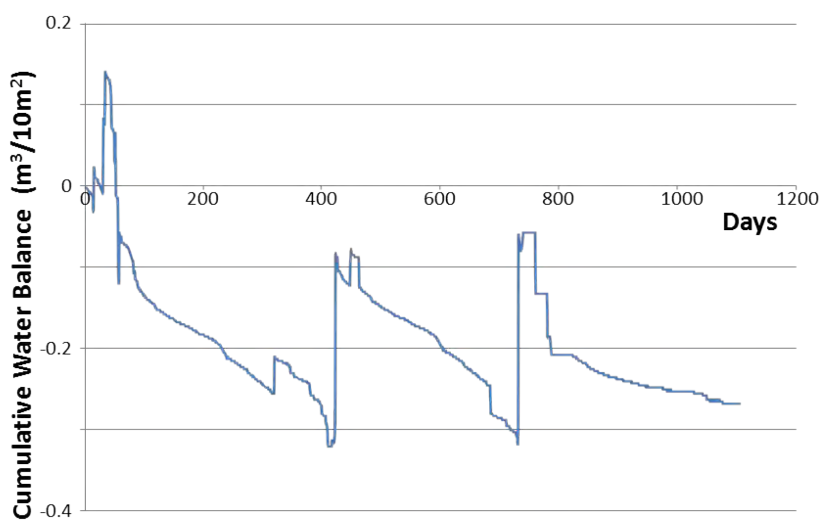


Figure 8.14 Cumulative water balance over model section (10 m x 1m)

the previous proponents, it may be advisable to develop a detailed cover design and re-model the results taking into consideration data from analogs with similar climate.

As the hydrodynamic system is driven by evaporation, a more likely (albeit still very low probability) impact arises from the possibility that the cover system has sufficient capillarity to transfer the tailings pore solutes upwards into the cover materials, thus threatening the effectiveness of revegetation. Cover trials planned at the closure of tailings pond 1 are intended to explore the requirements for a capillary break as potential mitigation for this scenario.

8.9.2 Cover Design

The final design of the closure cover would be developed during the project design phase and presented to the DMP in the TSF Design Report, which must be approved before the commencement of construction. The design will be proved with cover trials carried out on the first cells closed (cells 1 to 5) some 7 to 10 years after operations commence. As noted previously, the goals of the cover will be discussed with regulators but will certainly include the reduction of infiltration, radon emanation while maximising runoff with minimal erosion.

The cover of the tailings storage facility will be revegetated. The aim of the revegetation will be to promote soil stability and to create a functioning ecosystem. In 2004 an area previously disturbed by the trial mining activites was rehabilitated. Rehabilitation was monitored, using formal assessment tools such as ecosystem functional analysis, through to 2009 and there is evidence that the revegetation techniques used have been successful. The rehabilitation will continue to be assessed and will inform the revegetation plans for the TSF.

Refer to the PER, Mine Closure Plan for further information.

8.9.3 Detailed Design of Closure cover

The final design of the closure cover would be developed during the project design phase and presented to the DMP in the TFS Design Report which must be approved before the commencement of construction. The design will be proved with cover trials carried out on the first cells closed (Cells #1 - #5) beginning some 8 years after mill operations commence.

Refer to the PER, Mine Closure Plan for further information.

8.9.4 *Revegetation*

The cover of the tailings storage facility will be revegetated. The aim of the revegetation will be to promote soil stability and to integrate the area into the existing ecosystem. In 2004 an area previously disturbed by the trial mining activities was rehabilitated. Rehabilitation was monitored, using formal assessment tools such as ecosystem functional analysis, through to 2009 and there is evidence that the revegetation techniques used have been successful. The rehabilitation will continue to be assessed and will inform the revegetation plans for the TSF.

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