6 Best Practicable Technology

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TABLE OF CONTENTS

6 BEST PRACTICABLE TECHNOLOGY 6-1

6.1 Introduction 6-1

6.2 ALARA and BPT 6-3

6.3 Ranking and criteria of BPTs 6-4

6.4 Completed BPTs 6-7

6.5 Active BPTs 6-11

6.6 Future BPT assessments 6-15

REFERENCES 6-16

FIGURES

Figure 6-1 Framework for the integration of risks from multiple hazards into a holistic ALARA demonstration (source: Bryant et al, 2017) 6-4

Figure 6-2 Illustration of stages 1-3 of Pit 3 capping Option D (Hatch, 2021) 6-13

Figure 6-3 Illustration of stage 4 of Pit 3 capping Option D (Hatch, 2021) 6-14

Figure 6-4 Illustration of stages 4 - 6 of Pit 3 capping Option D (Hatch, 2021) 6-14

Figure 6-5 Illustration of stages 7 - 8 of Pit 3 capping Option D (Hatch, 2021) 6-15

TABLES

Table 6-1: Explanation of relevant matters to be included in BPT assessment 6-2

Table 6-2 Summary of completed BPTs 6-8

Table 6-3 Summary of Pit 3 Capping Best Practicable Technology 6-11

Table 6-4 BPT Assessment Results: 6-12

APPENDICES

Appendix 6.1: Completed Best Practicable Technology Assessments 6-17

Appendix 6.2: BPT Assessment Matrices for Pit 3 Capping 6-18

Appendix 6.3: ALARA 6-19

Cover photograph: Ping Lu, Megan Parry and Lucia Lynch monitoring Pit 1 plantings

GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
As low as reasonably achievable	Abbreviated to ALARA. As low as reasonably achievable, economic and social factors being taken into account.
Best Practicable Technology	Technology from time to time relevant to the Ranger Project which produces the maximum environmental benefit that can be reasonably achieved having regard to all relevant matters.
Environmental Requirements	The Ranger Environmental Requirements are attached to the s.41 Authority and set out Primary and Secondary Environmental Objectives which establish the principles by which the Ranger operation is to be conducted, closed and rehabilitated and the standards that are to be achieved.

ABBREVIATIONS AND ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
ALARA	As Low As Reasonably Achievable
BPT	Best Practicable Technology
ER	Environmental Requirements
ERA	Energy Resources of Australia
RL	Relative Level
RPA	Ranger Project Area

6 BEST PRACTICABLE TECHNOLOGY

6.1 Introduction

A Best Practicable Technology (BPT) is a process of analysing currently available technologies against specified criteria to identify the preferred option or approach for undertaking major closure activities at the mine.

The identification and use of Best Practicable Technologies (BPTs) are a key component of the legal framework for the closure of the Ranger Mine. The process is used to support applications to the Minesite Technical Committee (MTC) and to demonstrate that impacts on the Ranger Project Area (RPA) are as low as reasonably achievable (ALARA). The Ranger Authorisation requires that "All mining operations shall be implemented in accordance with BPT" and that impacts on the RPA are ALARA. In compliance with this requirement, a BPT assessment has accompanied each proposal for consideration by the MTC. This has been the basis upon which the MTC has made its recommendations to the Minister to approve major closure activities.

The use of a BPT assessment was identified in the Ranger Authorisation (Annex A, Section 12.4) as '*that technology from time to time relevant to the Ranger Project which produces the minimum environmental pollution and degradation that can reasonably be achieved having regard to:*

- the level of effluent control achieved, and the extent to which environmental pollution and degradation are prevented, in mining and milling operations in the uranium industry anywhere in the world,
- the total cost of the application or adoption of that technology relative to the environmental protection to be achieved by its application or adoption,
- evidence of detriment, or of lack of detriment, to the environment after the commencement of the Ranger Project,
- the physical location of the Ranger Project,
- the age of equipment and facilities in use on the Ranger Project and their relative effectiveness in reducing environmental pollution and degradation, and
- social factors including possible adverse social effects of introducing new technology.'

The interpretation and subsequent development of an assessment method was undertaken by the Supervising Scientist Division and published in their 2000-2001 Annual Report (Supervising Scientist, 2001). This was built upon and further refined for tailings integration and water management by Johnston and Iles (2013) after being accepted by stakeholders in

2012[2]. The current ER definition of BPT and an explanation of how each BPT is employed in the assessment is presented in Table 6-1.

Table 6-1: Explanation of relevant matters to be included in BPT assessment

Environmental Requirement Clause	Explanation
BPT is defined as: That technology from time to time relevant to the Ranger Project Area which produces the maximum environmental benefit that can be reasonably achieved having regard to all relevant matters including:	BPT: That technology that ranks highest when assessed against the identified factors and is consistent with the Primary Environmental Objectives
(a) the environmental standards achieved by uranium operations elsewhere in the world with respect to (i) level of effluent control achieved; and (ii) the extent to which environmental degradation is prevented;	World's Best Practice: Options are compared with the environmental standards set by world's best practice in uranium mining and milling at the time of implementation, with respect to the level of effluent control achieved and the prevention of environmental degradation.
(b) the level of environmental protection to be achieved by the application or adoption of the technology and the resources required to apply or adopt the technology so as to achieve the maximum environmental benefit from the available resources;	Cost-effectiveness: Options are assessed with respect to both the level of environmental protection achieved and the cost of implementation.
(c) evidence of detriment, or lack of detriment, to the environment;	Proven effectiveness: Proposals for which there is practical evidence of their effectiveness are favoured over proposals for which there is only experimental or theoretical evidence.
(d) the physical location of the Ranger Project;	Location: The Ranger Mine is located in the wet-dry tropics of the Northern Territory, on Aboriginal land surrounded by Kakadu National Park, approximately 260km east of Darwin. The level of protection required for the environment and community is very high and the technology chosen is designed accordingly.
(e) the age of equipment and facilities in use on the Ranger Project and their relative effectiveness in reducing environmental pollution and degradation; and	Age of equipment: Technology in use is reviewed routinely to determine whether recent advances have been made that would result in enhanced environmental protection. Technology installed at the Ranger Mine in accordance with BPT is then reasonably allowed to fulfil its serviceable life with due consideration given to the advances in technology and the amount of serviceable life expended.

[2] MTC meeting February 2012

Environmental Requirement Clause	Explanation
(f) social factors including the views of the regional community and possible adverse effects of introducing alternative technology.	Social factors: The views of the regional community are incorporated into BPT assessment. This includes where the introduction of new technology may improve the level of environmental protection but may also have negative social consequences. Benefits in environmental effectiveness may not necessarily result in greater social acceptability.

6.2 ALARA and BPT

As noted above, the BPT process is used to demonstrate that impacts on the RPA are as low as reasonably achievable (ALARA). The ALARA concept comes from the field of radiation protection but can also be applied to non-radiation hazards. Figure 6-1 illustrates the framework that ERA uses to apply ALARA. ERA uses the BPT process to achieve the step in this framework that is labelled ‘Optioneering’.

Section 6.3 describes the criteria used and the ranking system applied to the options included in a BPT assessment. Selected options from the BPT process are then carried through the remainder of the steps in Figure 6-1 to demonstrate acceptability from the perspective of ALARA (Appendix 6.3).

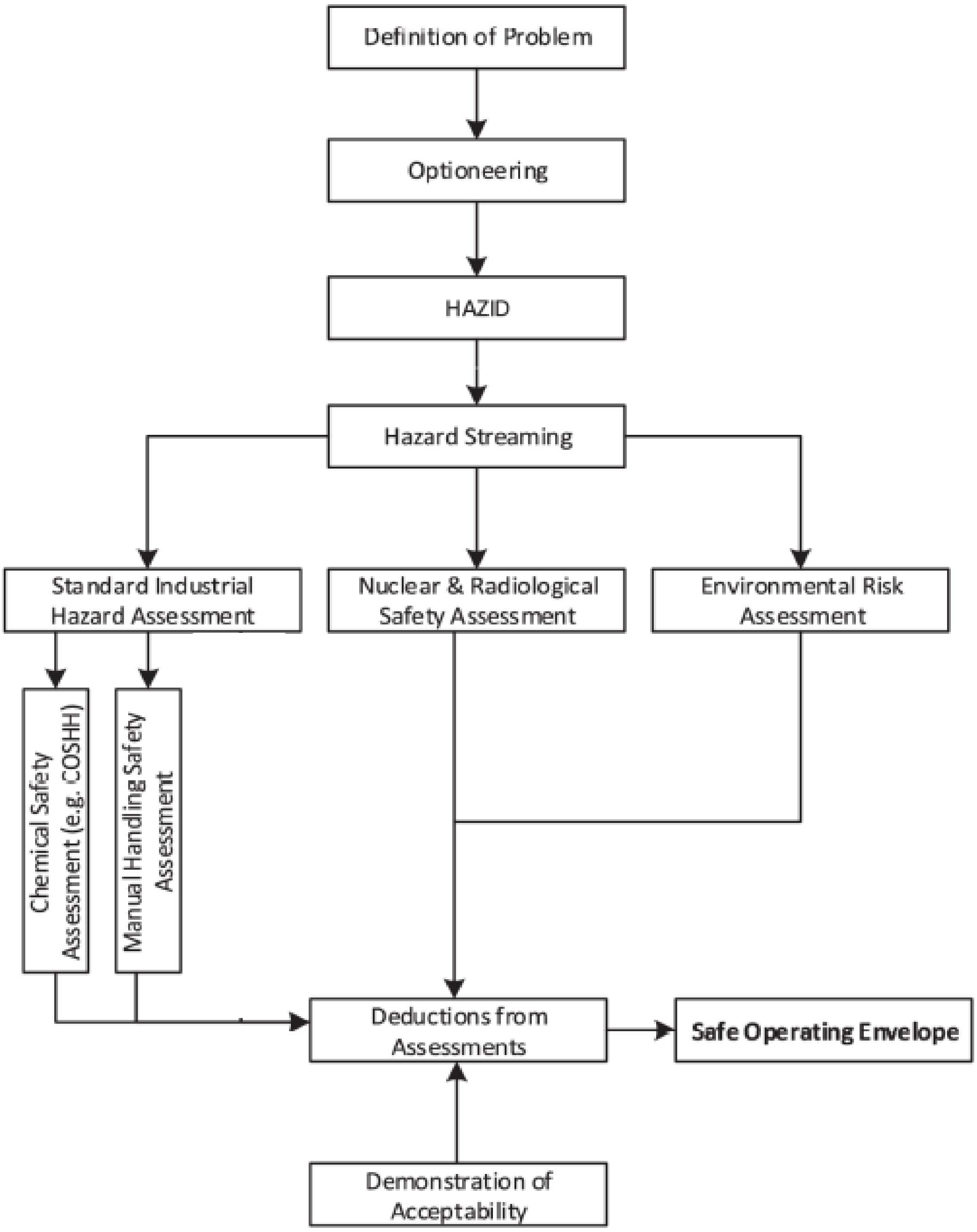

Figure 6-1 Framework for the integration of risks from multiple hazards into a holistic ALARA demonstration (source: Bryant *et al*, 2017)

6.3 Ranking and criteria of BPTs

Each BPT option is ranked against each criteria using a 5-level ranking system as follows:

- Rank 1 – Inadequate: the option does not meet current standards and it is unlikely that modifications could reverse this assessment

- Rank 2 – Poor: the option does not meet current standards but options for modifications exist that could reverse this assessment
- Rank 3 – Acceptable: the option meets current standards
- Rank 4 – Good: the option exceeds current standards
- Rank 5 – Excellent: the option exceeds current standards by a substantial margin and the option is recognised as international best practice.

If insufficient information is available to allocate a rank to a criterion in the early stages of the BPT process, the criterion shall be given an 'unable-to-evaluate' assessment. This will then prompt the development of actions to address the lack of knowledge to ensure that sufficient information will be available for evaluation prior to the application being submitted to the MTC. Where it is assessed that the criterion is not applicable (NA) to an option being considered, a 'NA' result is recorded.

Additional to the 5-level ranking system, 'show-stoppers' may also be assigned:

- A hard show-stopper is allocated to an option where it was clear from basic initial consideration that the option could not be accepted and there was no need to proceed further with assessment of the option. This might occur, for example, if an option could result in intrusion on a sacred heritage site.
- A soft show-stopper is recorded against an option if a rank equal to one or two was attributed to the option for any criterion involving occupational health and safety issues, off-site environmental protection or cultural issues. The recording of a soft show-stopper against an option would not be considered to rule out that option but it would record that the performance of the option against the particular criterion would need to be reviewed and improved before the option could be considered acceptable. The recording of a significant number of soft show-stoppers against an option would, however, be likely to rule the option out of further consideration.

A BPT score is generated for each technology option. The score is calculated using the rank against each applicable criterion, whereby:

- an option that achieves the highest possible rating for all criteria would score 100
- an option that meets standards for all criteria would score 0
- an option that achieves the lowest possible rating for all criteria would score -100.

The criteria against which each option is ranked are:

- Traditional Owner culture and heritage:
  - Would the adoption of the option have adverse impacts on the cultural practices, traditions and customs of the local Aboriginal communities?
  - Would the option threaten, in any way, the integrity of sacred sites, rock art or any other aspect of the cultural heritage of the region?

- Protection of people and the environment:
  - Would the option give rise to adverse impacts on the health and safety of Aboriginal or non-Aboriginal members of the local community?
  - Would the option have any adverse socio-economic impacts on the communities in the town of Jabiru or in the broader Kakadu region?
  - Would the option achieve protection of the natural World Heritage and Ramsar status of Kakadu NP?
  - While disturbance and environmental impact is inevitable on the project area, would adoption of the option minimise such onsite impacts?
- Fit for purpose:
  - Does the option use proven technology? Proven and demonstrated technology would be ranked higher than very new, unproven or theoretical technology.
  - How effective is the technology used in the option in meeting its desired output objective? Effective, highly robust options would rank highly.
  - How robust or sensitive is the option to variation in external factors such as weather and relevant factors (e.g. expected ground strengths, result of predecessor activities, higher or lower flows)?
  - Does the standard of environmental protection achieved by the option meet the highest standards achieved in uranium mining elsewhere in the world?
- Operational adequacy:
  - Would adoption of the practice ensure the ongoing health and safety of the workforce?
  - Would the option require extensive control and support effort to construct?
  - Is the process operationally reliable? That is, will it have high availability, or will it have features whose inherent sensitivity may impact availability?
  - Would the option be difficult to maintain?
  - Would the complexity of construction create cost risks arising from schedule uncertainty?
- Rehabilitation and closure:
  - Would adoption of the option result in closure costs that significantly detract from overall project value?
  - Would the option promote or detract from the ability to:
    - Revegetate the mine site with local native species and resulting in a low maintenance regime?
    - Establish stable radiological conditions that will ensure health risks to the public from the principal exposure pathways are ALARA?

  - Establish erosion characteristics on the site that, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas?
  - Meet agreed water quality criteria in creeks draining the mine site and achieve appropriate ecosystem restoration standards for water bodies on the rehabilitated landform?
  - Ensure that for 10,000 years all tailings produced at the Ranger site are physically isolated from the environment and contaminants arising from the tailings do not result in any detrimental environmental impact off the RPA?
  - Meet operational deadlines to achieve closure within a period that meets stakeholder expectations any legal requirements?
- Would adoption of the option extend closure beyond Traditional Owner expectations?

6.4 Completed BPTs

Table 6-2 provides a summary of the completed BPTs. Each of these BPTs were included in the 2020 MCP and the related on the ground activities have either been completed or have commenced. Appendix 6.1 details each of the completed BPTs and includes the accompanying matrices of assessment rankings.

Table 6-2 Summary of completed BPTs

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Approved
Integrated tailings, water and closure (ITWC)	9 – PFS1 8 – PFS2 (Stage 1) 4 - PFS2 (Stage 2) 8 – Supp ITWC	Dredging 1B/1C 1B A3	Tailings reclamation via Dredging Two options carried forward for brine injection Brine injection, thickened tailings and milling until 2020 Unthickened tailings with wicks to accelerate consolidation	41.3 (Supp ITWC)	2013-2016
Salt treatment and disposal	10	1B	8 options were assessed in Stage 1, the top 2 options plus 2 additional options were assessed in Stage 2. The preferred option is brine injection to the underfill without rock screening.	19	October 2018
Brine Squeezer	27	BM2	Addition of the Osmoflo Brine Squeezer to treat Water Treatment Plant (WTP) brines to minimise additions to the pond water and process water inventory, and to optimise pond and process water treatment and disposal mechanisms.	23.7	April 2019
Closure of ranger 3 Deeps	7 - Decline 3 - Portal 9 - Ventilation Shaft	A7 B2 C9	A7 Decline: waste rock placed only in the weathered zone (i.e. up to surface ~40 vertical m). B2 Portal: Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock. C9 Ventilation Shaft: Crushed waste rock up to weathered zone, then 10 m cemented rock fill and then 10 m of crushed rock to surface; concrete collar removed.	41.7 30.8 39.5	April 2019
Progress Pit 1 to final landform	Multiple	NA	Requirement to maintain pre-mining drainage and catchment areas and to ensure that it does not degrade unduly as a result of climate change. Each version of the landform undergoes landform evolution and erosion modelling by the SSB and is peer reviewed by ARRTC. The studies, reviews and	NA	May 2019

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Approved
			subsequent modelling done to address landform design and backfill planning are consistent with the general practice of BPT assessment.		
Tailings deposition into Pit 3 for Mill tailings and dredge tailings	3 Mill 4 Dredge	M2 D2	M1: Subaerial deposition from the current, multiple discharge points (one at a time, infrequently changing) D1: Dredge 1 and 2 subaerial	35.4 16.7	July 2019
Remnant tailings transfer – TSF to Pit 3	10	3	Scrape clean TSF floor and walls, transfer by truck, and deposit into Pit 3 south west end via a constructed tip head.	17	Included within tailings transfer approvals
High density sludge (HDS) plant recommissioning	12	11	No change to the method approved by DITT in February 2020. That is, indirect treatment by releasing HDS product into the pond water inventory (i.e. RP2), for subsequent treatment through any of the pond water treatment plants (WTPs).	44.4	February 2020
TSF North Notch Stage 3	6	A2	Construct North Notch 3 to RL 37.3 m (clay core RL 36.8 m) and construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0	June 2020
TSF subfloor material management	14	1a	Leave material *in situ.* TSF subfloor material left undisturbed in situ. All visible tailings removed. TSF is then used for process water storage.	38.2	August 2020
Blackjack (gear oil) waste disposal	5	A1	Transport the blackjack drums in containers via road trains to the selected geological repository (multi-barrier safety case) located at Sandy Ridge (WA) to permanently isolate the waste from the biosphere. The waste will be pre-treated to immobilise	50	NA

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Approved
			contaminants prior to disposal in a bed of low permeability clay.		

6.5 Active BPTs

It is noted that the remnant tailings transfer BPT was not complete at the time of writing the 2020 MCP. However, it is now complete and therefore has been included in the completed BPTs summarised in Table 6-2 and described more fully in Appendix 6.1.

This section focuses on the active BPT, being the Pit 3 capping. Table 6-3 provides a summary and a more detailed description follows.

Table 6-3 Summary of Pit 3 Capping Best Practicable Technology

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Status
Pit 3 Capping	7	D	Hybrid + East platform - Wicking completed sub-aqueously in Zone 1, 2, & 3 only. Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method in Zone 4 and perimeter. Sub-Aerial (passive dry out) Capping Method to cap Zone 1,2,3 after wicking.	23	Application submitted April 2022, feedback received, Application update in progress

As part of mine closure, Pit 3 capping is an integral activity as it is the permanent storage location of tailings, brine, demolition waste and a large quantity of waste rock. The originally planned method of capping relied on a series of assumptions relating to the form of the tailings at the completion of deposition into Pit 3. A key assumption was that the tailings would be largely homogeneous in nature, with a relatively consistent profile and low gradient across the pit floor. However, following the deposition of tailings into Pit 3, the actual form of the tailings did not fully align with the assumptions, in that:

- a coarse and solid beach was present at the eastern end, with a ‘hollow’ at the western end, and a gradient between the two extremities that exceeds the design basis of the capping methodology
- a layer of fine tailings was present across the pit, which behaves like a fluid. This surface body of fine tailings is of very low strength, which introduces additional complexity in terms of tailings encapsulation, capping execution and water management.

The actual tailings conditions added significant complexity to the capping methodology. As such, a BPT study was undertaken to define and assess a series of alternative capping methods that may reduce capping cost and schedule, reduce execution complexity and associated execution safety, and still achieve the relevant ERs.

The BPT assessment was conducted via a full day workshop on 22 October 2021, follow up sessions on 27 October 2021 and 26 November 2021, additional ranking assessments to resolve matters not fully addressed at the workshop/sessions, and additional solute transport modelling of high-ranking options. The BPT was documented in the report by Hatch (2021).

The options assessed, indication of risks and show-stoppers, and the final score for each option is presented in Table 6-4 (see Appendix 6.2 for details of rankings).

Table 6-4 BPT Assessment Results

Option	Option Description	Number of Class 3 & 4 Risks	Show-stoppers	Score
A	Sub-Aqueous Capping Method (Base case and current plan) Based on Golder Design and proposals from 3 x vendor execution proposals.	III: 10 IV: 2	Soft: 1 Hard: 0	7
B	East platform finished with Sub-Aqueous Capping Method (Option A) Build East platform on coarse tailings (old, beached area) to reduce capping area.	III: 11 IV: 2	Soft: 1 Hard: 0	7
C.1	Sub-Aerial (passive dry out) Capping Method Approx. 3 year dry out then capped (similar to Pit 1)	III: 5 IV: 2	Soft: 2 Hard: 0	20
C.2A	Sub-Aerial (accelerated dry out by mechanical assistance) with conventional wicking through bridging layer Capping Method Use mechanical assistance to accelerate dry-out, create crust, wick conventionally through bridging layer and Sub-Aerially Cap	III: 6 IV: 2	Soft: 1 Hard: 0	9
C.2B	Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method Use mechanical assistance to accelerate dry-out, create crust, and Sub-Aerially Cap	III: 6 IV: 2	Soft: 1 Hard: 0	18
C.2C	Sub-Aerial (accelerated dry out by mechanical assistance) with Amphibious wicking through mechanically assisted crust Capping Method Use mechanical assistance to accelerate dry-out, create crust, wick amphibiously through crust and Sub-Aerially Cap	III: 6 IV: 2	Soft: 1 Hard: 0	16
D	Hybrid + Eastern Platform Wicking completed sub-aqueously in Zone 1, 2, & 3 only. Use C.2B method to cap (no wicks) in Zone 4 and perimeter. Use a C.1 method to cap Zone 1,2,3 after wicking.	III: 5 IV: 2	Soft: 1 Hard: 0	23

All assessed options achieved a positive overall score and had no 'hard' show-stoppers. The preferred option, Option D, achieved the highest score with 23, followed closely by Option C1 with 20 points. Option D is a hybrid method which entails (Figure 6-2 to Figure 6-5):

- pump water from Pit 3 into the RWD until a wicking level is achieved (RL -17m water level, which equates to about 2m water depth);
- sub-aqueously install wick drains into specified wicking zones (Zones 1, 2, & 3 only) to accelerate consolidation and reduce the dry out period from ~3 years to ~2 years;
- pump remaining water from Pit 3 to RWD;
- build a platform on the Eastern tailings beach of the pit floor;
- mechanically assist drying of the pit floor in the non-wicked areas of the pit using amphirol (a screw propelled vehicle able to traverse soft sites) and swamp dozers to produce a crust-like material with a nominal thickness of 1-1.5m;
- install a geotextile separation layer;
- install bridging material sub-aerially using small equipment (1-2m thick layer of waste rock);
- install secondary capping layers (~2m thick layer with Moxie and D6, then heavy mine equipment (HME));
- bulk backfill of pit (using mine HME).

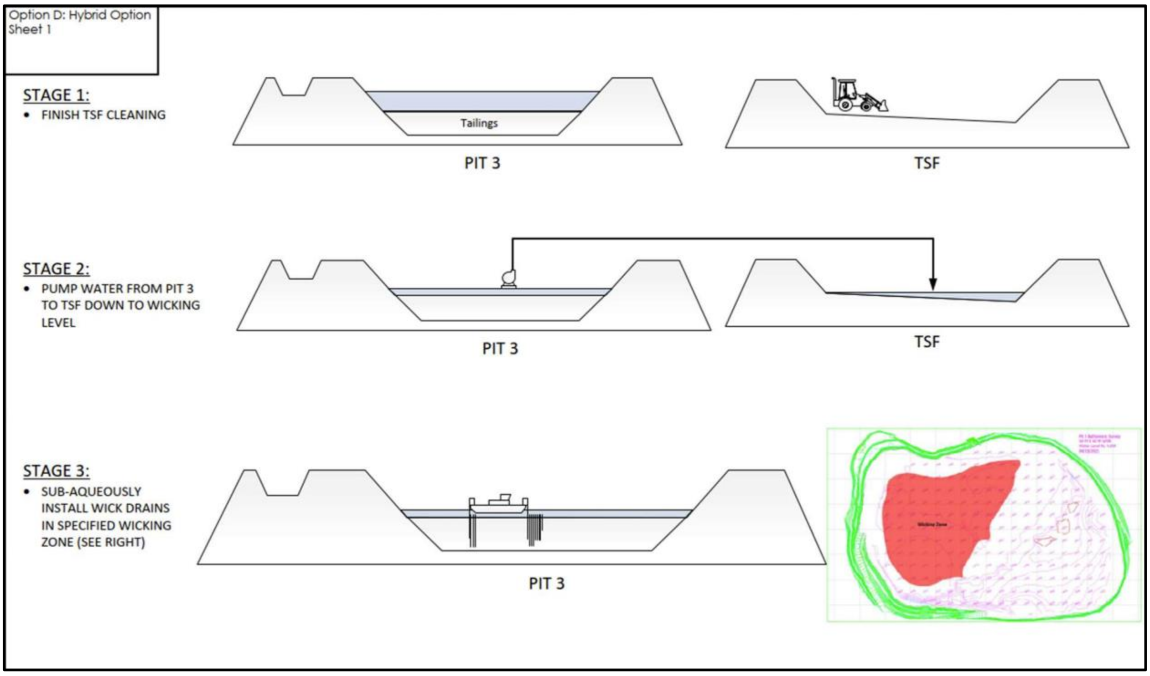

Figure 6-2 Illustration of stages 1-3 of Pit 3 capping Option D (Hatch, 2021)

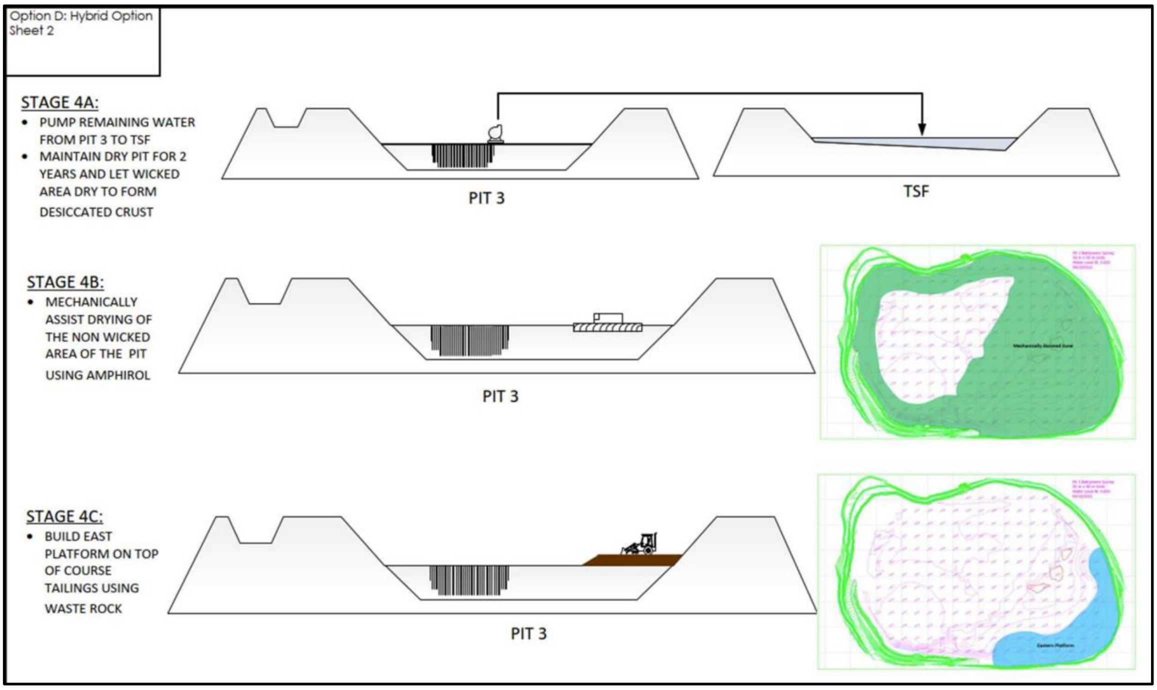

Figure 6-3 Illustration of stage 4 of Pit 3 capping Option D (Hatch, 2021)

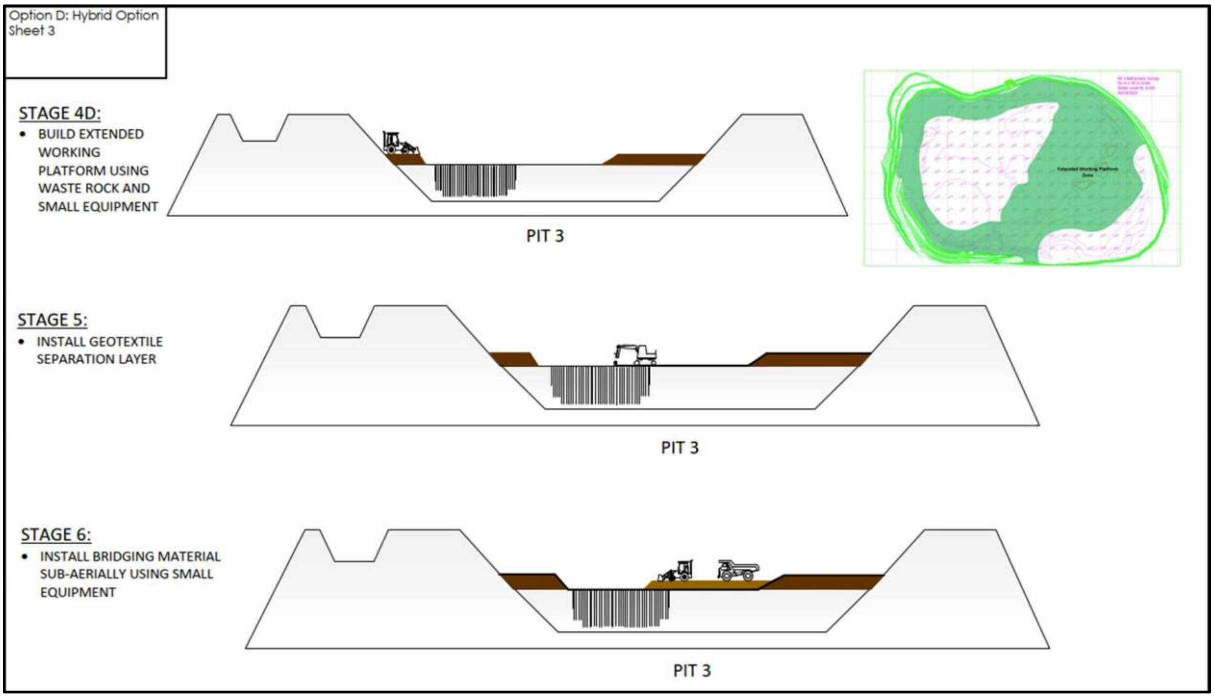

Figure 6-4 Illustration of stages 4 - 6 of Pit 3 capping Option D (Hatch, 2021)

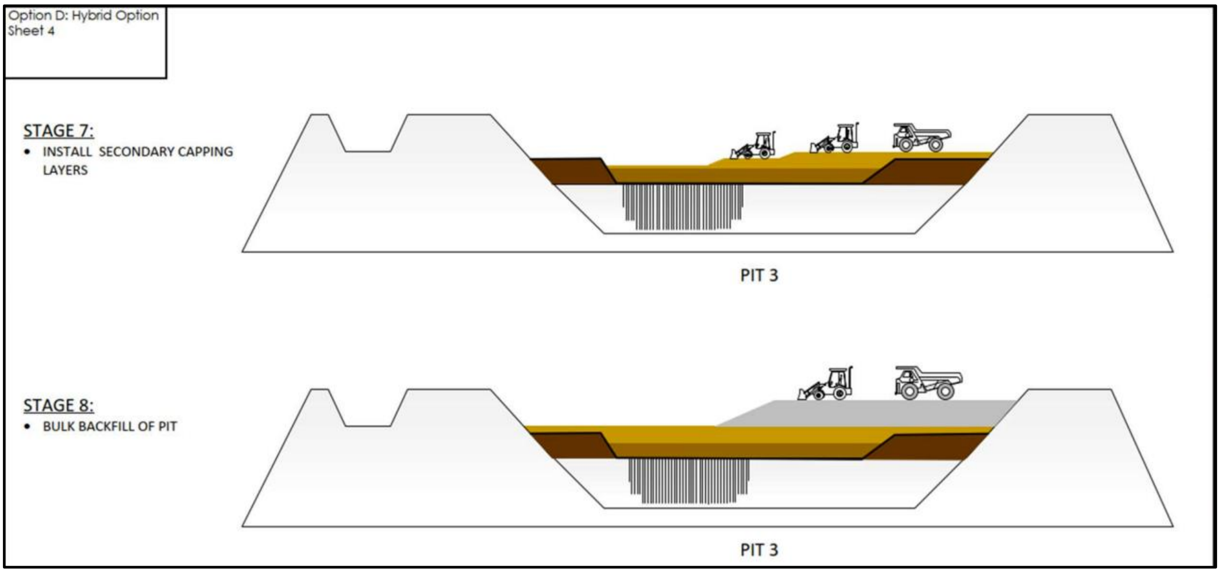

Figure 6-5 Illustration of stages 7 - 8 of Pit 3 capping Option D (Hatch, 2021)

The primary benefits of Option D are:

- that it enables the timing of demolition to be brought forward with the creation of the Eastern Platform, thereby providing a holding location for demolished material;
- the sub-aerial capping option was successfully executed in the closure of Pit 1 and uses more traditional and proven methods with lower risk; and
- the mechanically assisted development of a crust allows earlier access for capping and bulk material movement.

Based on the outcomes of the BPT assessment, the Pit 3 application was submitted to stakeholders for review in April 2022. The application is currently being revised following an adequacy assessment and feedback from stakeholders prior to resubmission.

6.6 Future BPT assessments

BPT assessments will be undertaken as required for future applications, and where any other further decisions on technology arise. Examples include the TSF/RWD deconstruction, Final Landform, and treatment/remediation of contaminated sites.

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APPENDIX 6.1: COMPLETED BEST PRACTICABLE TECHNOLOGY ASSESSMENTS

Energy Resources Of Australia

APPENDIX 6.1 Completed BPT Assessments

Contents

6.1 Salt treatment and disposal 2
6.2 Brine Squeezer 3
6.3 Ranger 3 Deeps 7
6.4 Progress of Pit 1 to final landform 16
6.5 Tailings management 17
6.5.1 Integrated tailings, water and closure – PFS 1 17
6.5.2 Integrated tailings, water and closure – PFS 2 19
6.5.3 Supplementary integrated tailings, water and closure prefeasibility study 22
6.6 Tailings deposition into Pit 3 for mill tailings and dredge tailings 24
6.7 Remnant tailings transfer 35
6.8 High Density Sludge plant recommissioning 35
6.9 TSF North Notch Stage 3 41
6.10 Tailings Storage Facility subfloor material management 45
6.11 Blackjack waste disposal 52
References 55

6.1 Salt treatment and disposal

The need to dispose of saline water is a common process in several industries and, as a result, 25 methods were identified as potential salt management options and were considered for the BPT assessment. Many of the options considered had fatal flaws for the Ranger mine and were hard show-stopped prior to the workshop. A total of seven options were assessed in detail (Table A6.1-1).

Table A6.1-1 Salt treatment and disposal options

Category	Brine injection	Crystallisation	Thermal distillation
Method	• pit 3 underfill • underground silos • pit 3 underfill with rock screening	• pit 3 placement • underground silos placement	• pit 3 underfill injection • underground silos injection

The overall outcome of the BPT assessment was that brine injection to the underfill without rock screening was the highest ranked alternative. Brine injection to underground silos scored well but concerns were identified on Occupational Health and Safety issues during both the construction and the operational phases of this option. Major problems were identified for the crystallisation and distillation options, and it is considered unlikely that either option assessed would be viable. The only uncertainty remaining for the preferred option related to the potential for reactivity between the brine and the waste rock of the underfill and possible limitation on the volume available for the storage of brine.

It was concluded that this issue required further assessment prior to a final decision on the salt management option to be implemented. For this reason, crystallisation was taken forward into the overall strategy assessment pending further testing to confirm the brine injection option.

6.2 Brine Squeezer

Report: *Application to operate a Brine Squeezer, 2019*

Water management is an environmentally and operationally relevant aspect of the Ranger Mine. Concentration and isolation of contaminants through water management is a significant component of the Ranger Mine closure program. In January 2019, ERA presented the results of studies into additional processing options, to the Director of Mining Operations, to support the installation of the selected option, the Brine Squeezer (ERA 2019b).

Treatment of pond water through the water treatment plants generates brines that are added to the process water inventory. This results in 200 to 1,000 ML/year of additional process water to be treated by the Brine Concentrator (BC). However, the Water Treatment Plant (WTP) brines are less concentrated than process water (less than 25 percent brine of process water concentration), and treatment options that are more cost effective than treating WTP brines as process water are available. Additional processing of WTP brines will reduce the volume added to process water, reducing the total inventory to be treated by the BC, and reducing overall risks to the closure schedule and costs associated with water treatment.

ERA investigated options to concentrate WTP brines over many years. Given the high scaling and membrane fouling potential of WTP brines, it was necessary to consider alternatives to standard reverse osmosis (RO). The implementation of the Osmoflo Brine Squeezer was established to be a cost-effective way to treat WTP brines as it minimised unnecessary additions to the pond water and process water inventory and optimised pond and process water treatment and disposal mechanisms.

To meet regulatory requirements of the Ranger Authorisation and facilitate the incorporation of novel technology at Ranger Mine, a thorough BPT assessment process was undertaken. This began in 2013 with a preliminary desktop screening assessment that investigated 27 options. From this assessment 15 options were hard show-stopped, whilst four options were soft show-stopped and four options scored poorly relative to the remaining four options, which were considered appropriate to progress for further assessment. A second, BPT assessment was then conducted in 2018 on:

- vibratory shear enhanced processing (VSEP);
- Brine Squeezer;
- electro dialysis reversal (EDR); and
- additional reverse osmosis (RO).

Using a 5-level technology ranking system where a ranking of three meets industry standards, the second BPT assessment showed the Brine Squeezer (Figure A6.1-1) to be the highest ranking option.

Pilot studies and test work were completed on two options: VSEP and Brine Squeezer. The results of these studies were used to inform the BPT assessment and revise the relevant criteria of the 2013 BPT assessment. The seven-month Brine Squeezer pilot study, completed in 2016,

conclusively demonstrated that this technology has the capability to treat the Ranger Mine pond water treatment brine, thus minimising the volume of brine and maximising the volume of release quality water on site.

This outcome had a significant influence on the 2018 BPT assessment scores for the Brine Squeezer, particularly against criteria such as *'Proven technology', 'Technical performance'* and *'Inherent Availability and Reliability'* compared to the other three technologies. The result is that during the 2018 BPT, the technology with the highest BPT score was the Brine Squeezer, followed by the EDR, VSEP and additional RO (Table A6.1-2 and following ranking matrices).

It has been demonstrated during field trials that WTP brine can be treated at up to 94 percent recovery of permeate of quality equal to, or better than, current WTP permeate. The plant, installed adjacent to the sand blast yard, comprises three trains, providing for 99 percent availability of two trains (1 standby/cleaning). Commissioning of the Brine Squeezer commenced in June 2019, with the plant now fully operational.

Table A6.1-2 Comparison of final BPT scores 2013 versus 2018

Option ID	Description	2013 BPT results	2018 BPT results
BM1	VSEP - Vibratory shear enhanced processing (FilTek)	18.8	13.2
BM2	Brine squeezer (Osmoflo)	21.9	23.7
BM3	EDR - electro dialysis reversal	30.0	19.4
BM6	Additional reverse osmosis	31.3	11.1

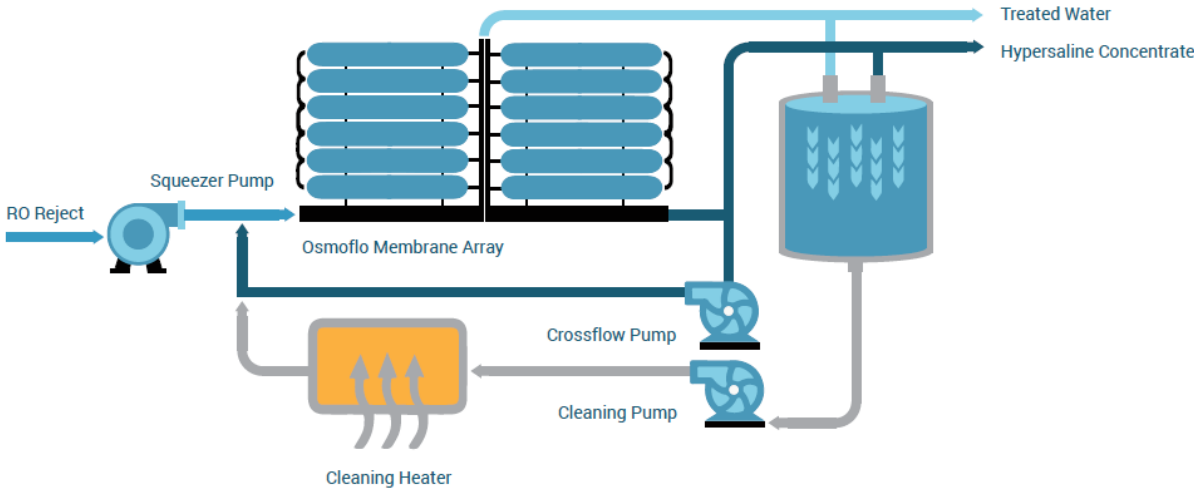

Figure A6.1-1: Brine Squeezer process flow diagram (source: http://www.osmoflo.com/)

BM Brine Minimisation

Option ID	Option Description	Revegetation	Radiation	Erosion	Water Quality	Tailings	Schedule	Cost	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction Complexity
		Rehabilitation and Closure							Constructability		
		Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
		1	1	1	1	1	1	1	1	1	1
BM1	VSEP (FilTek)	NA	NA	NA	NA	NA	3	4	4	4	3
BM2	Brine Squeezer (Osmoflo)	NA	NA	NA	NA	NA	3	4	4	4	3
BM3	EDR - Electro dialysis reversal	NA	NA	NA	NA	NA	3	4	4	4	3
BM6	Additional RO (includes pre-treatment step)	NA	NA	NA	NA	NA	3	3	4	4	3

	Inadequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to this option
Rank	1	2	3	4	5	UTE	NA

BM Brine Minimisation

Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Socio-economic impact local community	Ecosystems of Kakadu	Ecosystems of Project Area	Long-term Protection of Environment
					TO Culture & Heritage		Protection of People and the Environment				
		Show stopper column setting			Yes	Yes	Yes	No	Yes	No	Yes
				Rank weighting	1	1	1	1	1	1	1
BM1	VSEP (FilTek)	0	0	13.2	NA	NA	4	3	4	4	NA
BM2	Brine Squeezer (Osmoflo)	0	0	23.7	NA	NA	4	3	4	4	NA
BM3	EDR - Electro dialysis reversal	0	0	19.4	NA	NA	4	3	4	4	NA
BM6	Additional RO (includes pre-treatment step)	0	0	11.1	NA	NA	4	3	4	3	NA

6.3 Ranger 3 Deeps

Report: *Application Ranger 3 Deeps Exploration Decline Decommissioning, 2018*

In May 2012, phase 1 construction works of the Ranger 3 Deeps (R3D) decline began after being approved in September 2011. This allowed for underground exploration that could provide further information regarding the viability of the proposed R3D underground mine. An additional application was submitted for phase II construction works and was approved for the extension to the exploration decline, installation of a ventilation shaft, and acquisition of bulk samples on 4 June 2013.

Exploration in the decline (Figure A6.1-2) continued until December 2014, whilst submissions were made for the construction of the R3D underground mine at the same time. In October 2014, a draft environmental impact assessment (EIS) was submitted but, following an ERA board decision in June 2015, the statutory assessment process for the proposed R3D mine was halted and the decline was placed in long-term care and maintenance.

The primary objective of the BPT assessment was to determine which combination of options was best practice for the closure of the exploration decline. For the assessment, the decline was divided into three closure areas:

- main decline (2,710 m) – seven BPT closure options assessed;
- portal (185 m) – three BPT closure options assessed; and
- ventilation shaft (located at -260 mRL; vertical length 280 m) – nine BPT closure options assessed.

The BPT assessment rankings reflect known hydrogeological conditions obtained during decline construction and core sampling of resource holes, and subsequent hydrological modelling completed by INTERA (2018). The assessment also took into consideration ground conditions and potential heavy mobile equipment limitations (e.g. gradient, manoeuvrability). The assessed option and BPT outcomes are presented in Table A6.1-3 and the ranking matrices at the end of this sub-section.

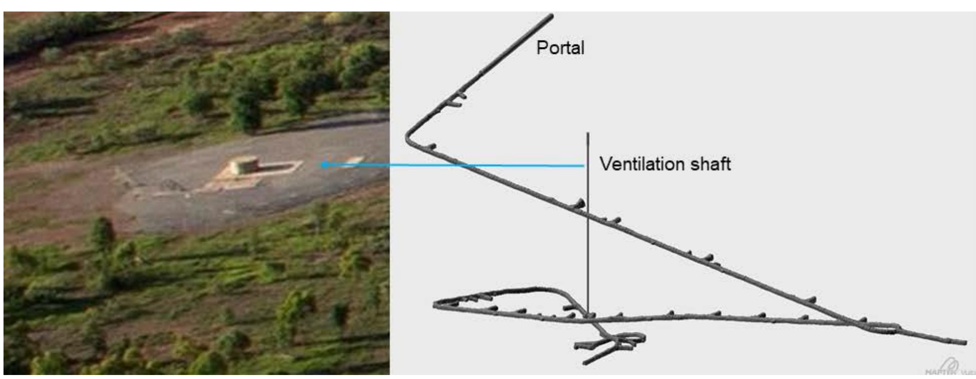

Figure A6.1-2: Aerial view of the ventilation shaft and underground infrastructure

Table A6.1-3: Decline options and best practicable technology assessment summary

Option	Option Description	Overall Rank
Decline closure (2,710 m)		
A1	Waste rock (full decline) and grouting of open holes	16.7
A2	A1 + bulkheads	12.5
A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~40 vertical m)	29.2
A4	A3 with cemented rock fill (CRF) instead of waste rock	25.0
A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	20.8
A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	-4.2
A7	A3 (without grouting of open holes and bulkheads)	41.7
Portal (185 m)		
B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	-11.5
B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	30.8
B3	Leave entire portal *in situ* and cover with waste rock	-10
Ventilation shaft		
C1	Waste rock; concrete collar removed	-100
C2	Waste rock, concrete *in situ*	-100
C3	Crushed waste rock; concrete collar removed	31.6
C4	Crushed waste rock; concrete collar *in situ*	-100
C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	21.1
C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar *in situ*	-100
C7	Steel plate; concrete collar removed and allow to flood	13.2
C8	Steel plate and allow to flood; concrete collar *in situ*	-100
C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	39.5

Main Decline closure

For the decline, options A1 and A2 rated poorly in comparison to the other options and were soft show-stopped based on occupational health and safety (OHS) concerns, cost and operability. Three options, scoring similarly, with one of these, A5, eliminated due to cost and reliability concerns. Option A6 was eliminated due to OHS and fitness for purpose. Option A7 (waste rock placed in the weathered zone) was allocated the highest assessment score of 41.7 and selected as the preferred option.

Portal closure

For the portal closure, B1 was ranked inadequate due to difficulty and complexity. Option B3 was rejected when it became apparent that the waste rock proposed to cover the portal would not blend with the final landform and therefore at odds with the cultural criteria. Option B2 (partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock) with a score of 30.8 and no show-stoppers, was ranked the highest and selected as the preferred option.

Ventilation shaft closure

Five of the ventilation shaft options were hard show-stopped based on fitness for purpose or cultural criteria (specifically visual amenity). Two options recorded soft show-stoppers for cultural criteria (also visual amenity) and two options, C3 and C9 scored closely on the BPT assessment. For its greater ability to mitigate potential long-term movement of groundwater to the surface via the ventilation shaft, option C9 (crushed waste rock up to weathered zone, then ten metres cemented rock fill and then ten metres of crushed rock to surface; concrete collar removed) was identified as the highest ranking option with a score of 39.5 and selected as the preferred option.

						TO Culture & Heritage		Protection of People and the Environment			
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture ("Location")	Cultural heritage ("Location")	Community Health & Safety ("Social factors")	Socio-economic Impact on Local Communities ("Social factors")	Ecosystems & Natural world heritage values of Kakadu National Park ("Location" & "Proven effectiveness")	Ecosystems of the Project Area ("Location")
	Decline closure (2,710 m)				0.0						
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	NA	NA	4	3	5	3
	A2	A1 + bulkheads	0	1	12.5	NA	NA	4	3	5	3
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	NA	NA	4	3	5	3
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	NA	NA	4	3	5	3
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	NA	NA	4	3	5	3
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	NA	NA	1	3	5	1
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	NA	NA	4	3	5	3
	Portal (185 m)				0.0						
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	NA	NA	4	3	5	3
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	NA	NA	4	3	5	3
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0	1	NA	4	3	5	1
	Vent shaft				0.0						
1	C1	Waste rock; concrete collar removed	1	0	-100.0						
1	C2	Waste rock, concrete in situ	1	0	-100.0						
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	4	4	3	4	3
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0	1	1				

						TO Culture & Heritage		Protection of People and the Environment			
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture ("Location")	Cultural heritage ("Location")	Community Health & Safety ("Social factors")	Socio-economic Impact on Local Communities ("Social factors")	Ecosystems & Natural world heritage values of Kakadu National Park ("Location" & "Proven effectiveness")	Ecosystems of the Project Area ("Location")
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	2	2	4	3	4	3
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0	1	1				
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	2	2	4	3	4	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0	1	1				
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	5	5	4	3	4	3

						Fit for Purpose				Operational Adequacy			
			Show stopper column setting			No	No	Yes	No	Yes	No	No	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology ("Age/effectiveness of equipment")	Robustness ("Age/effectiveness of equipment")	Environmental Protection ("World's best practice" & "Proven effectiveness")	CAPEX / OPEX ("Cost effectiveness")	Occupational Health & Safety	Operability	Inherent availability and reliability (e.g. crusher availability)	Maintainability
	Decline closure (2,710 m)				0.0								
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	5	4	4	2	2	2	3	NA
	A2	A1 + bulkheads	0	1	12.5	4	4	5	1	2	2	3	NA
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	4	4	4	3	4	3	3	NA
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	4	4	4	2	4	3	3	NA
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	4	4	4	2	4	3	2	NA
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	1	1	1	5	4	5	5	NA
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	4	4	4	4	4	4	4	NA
	Portal (185 m)				0.0								
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	1	4	4	1	1	1	2	NA
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	4	4	4	3	3	3	4	NA
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0								
	Vent shaft				0.0								
1	C1	Waste rock; concrete collar removed	1	0	-100.0	1							
1	C2	Waste rock, concrete in situ	1	0	-100.0	1							
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	3	3	4	3	3	3	5
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0								

Initial show stopper	Option ID	Option Description (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology ("Age/effectiveness of equipment")	Robustness ("Age/effectiveness of equipment")	Environmental Protection ("World's best practice" & "Proven effectiveness")	CAPEX / OPEX ("Cost effectiveness")	Occupational Health & Safety	Operability	Inherent availability and reliability (e.g. crusher availability)	Maintainability
						Fit for Purpose				**Operational Adequacy**			
			Show stopper column setting			No	No	Yes	No	Yes	No	No	No
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	5	3	4	2	3	3	3	5
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0								
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	1	3	3	5	3	4	5	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0								
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	5	3	4	3	3	3	3	5

Initial show stopper	Option ID	Option Description (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation ("Location")	Radiation ("Location")	Erosion ("Location")	Water ("Location")	Schedule
			Show stopper column setting			Yes	Yes	Yes	Yes	No
						Rehabilitation and Closure				
	Decline closure (2,710 m)				0.0					
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	NA	NA	NA	NA	3
	A2	A1 + bulkheads	0	1	12.5	NA	NA	NA	NA	3
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	NA	NA	NA	NA	3
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	NA	NA	NA	NA	3
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	NA	NA	NA	NA	3
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	NA	NA	NA	NA	3
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	NA	NA	NA	NA	3
	Portal (185 m)				0.0					
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	4	NA	NA	NA	3
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	4	NA	NA	NA	3
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0					
	Vent shaft				0.0					
1	C1	Waste rock; concrete collar removed	1	0	-100.0					
1	C2	Waste rock, concrete in situ	1	0	-100.0					
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	5	3	4	3
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0					
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	4	5	3	4	3

						Rehabilitation and Closure				
			Show stopper column setting			Yes	Yes	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation ("Location")	Radiation ("Location")	Erosion ("Location")	Water ("Location")	Schedule
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0					
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	2	5	3	4	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0					
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	4	5	3	4	3

6.4 Progress of Pit 1 to final landform

Report: *Application of Progress Pit 1 Final Landform, 2019*

To support progress of the Pit 1 final landform, additional work was undertaken to address Supervising Scientific Branch (SSB) comments (Department of the Environment and Energy 2018) on an earlier change application (ERA 2018a). Works included:

- a risk assessment undertaken to update the 2016 risk assessment;
- solute mass balance and water balance;
- soil-vegetation-atmosphere modelling to estimate plant available water under various conditions;
- revision of the final landform cover on Pit 1 to maximise plant available water;
- review of research relevant to rehabilitation of the Ranger Mine;
- preliminary flood modelling and hydraulic design work were updated and refined from work in 2017 to create a Digital Elevation Model (DEM); and
- erosion and sediment control features were refined based on conceptual designs developed in 2017.

The digital elevation model (DEM) was also provided to the MTC for assessment and SSB feedback was included in the change application report (ERA 2019a). The Pit 1 Progressive Rehabilitation Monitoring Framework was developed to facilitate successful rehabilitation of Pit 1 and inform ongoing rehabilitation across the RPA. These additional works supported ERAs continued backfilling of Pit 1 ahead of the initial tree planting of the Pit 1 landform surface.

An application was submitted to the Director of Mining Operations, DITT in March 2019 in accordance with the requirements of the Ranger Authorisation issued under the *Mining Management Act* (NT) and was approved in May 2019.

During the life of Pit 1, ERA has undertaken many studies and BPT assessments, including:

- assessment of the selected tailings deposition options for Pit 1, to ensure the long-term stability of tailings as part of the final rehabilitated landform in 1994;
- assessment of seepage limiting options in 2005; and
- closure studies undertaken as part of a 2008 PFS, 2009 feasibility study and further review and validation of the preferred Pit 1 closure option as part of the ITWC prefeasibility study in 2012.

Landform design has involved several iterations of the post-closure landscape models over the life of the mine with significant options analysis and refinement of the landscape reconstruction over several years. Through supporting investigations and thorough refinement processes, the backfilling option being implemented is optimal. In particular, bulk backfilling of Pit 1 has been completed using the selected bulk backfill methodology.

6.5 Tailings management

6.5.1 Integrated tailings, water and closure – PFS 1

Report: *Integrated, Tailings, Water & Closure Prefeasibility Study (ITWC PFS): Analysis of Best Practicable Technology, 2013*

The focus of the ITWC PFS program was to evaluate the technology for reclamation, treatment and transfer of tailings from the TSF to the mined-out Pit 3, and salt management technology to ensure physical containment of brine (from the BC treatment of process water) within Pit 3 with no detrimental impact to the environment for a period of 10,000 years as required by the ERs.

Options were considered for the reclamation, treatment and deposition of tailings for mine closure, which are described in the sub-sections below.

Tailings reclamation

Three categories were considered for reclamation of tailings from the TSF: excavation, hydraulic mining and dredging. Each category had a subset of transfer options, giving a total of nine options taken into the BPT assessment (Table A6.1-4 and the ranking matrices at the end of Section 6.5).

Table A6.1.4: Tailings reclamation options

Category	Excavation	Hydraulic Mining	Dredging
Transfer options	• dewater and truck • dewater and conveyor • slurry and pump	• pump • thickener and pump	• pump • thickener and pump • thickener, filtration and truck • thickener, filtration and conveyor

Of the reclamation and transfer options, excavation rated poorly compared with hydraulic mining and dredging. The principal deficiencies identified were the sensitivity of excavation techniques to extreme rainfall events, environmental protection and OHS issues arising from dust from the disturbed tailings, the considerable operational effort that would be required, and the drainage requirements required for successful implementation of the process. Hence, excavation was rejected as a method for reclamation of tailings from the TSF.

Hydraulic mining and dredging emerged from the workshop with approximately equal BPT assessment scores. An overall assessment of the relative significance of the various advantages and disadvantages of the two options led to the conclusion that the disadvantages of the dredging option (operability, maintainability, radiation protection) are much more amenable to management than those associated with hydraulic mining (sensitivity to extreme rainfall, environmental protection, high capital costs). This is particularly the case for the issue of sensitivity to extreme rainfall events where management options are extremely limited, and the occurrence of such events could have a major impact on the rehabilitation schedule. For this reason, dredging was selected as the preferred option.

Tailings treatment

The principal technical advantage of filtration is the reduced time required for tailings consolidation. It was thought to have some advantages for long-term dispersal of contaminants in groundwater, but this was yet to be demonstrated and the advantage was considered to be small. Disadvantages of this option included high costs to construct, install and operate, and the high maintenance requirements. The assessment outcome of filtration at the tailings workshop was that the option should be retained for whole-of-project BPT assessment, but it appeared to be a very expensive option with limited advantages.

Cementation was considered an option to potentially reduce dispersion of solutes in groundwater if required[1], however, it did not emerge as a viable treatment option. Further trials would be required, capital costs would be high because of the need to include filtration as a preliminary step, and operational costs would be extremely high as a result of the high cement consumption implicit in the process.

Tailings deposition

Options assessed for deposition of tailings into Pit 3 considered either subaerial or subaqueous techniques for thickened tailings and dry stacking or co-disposal with waste rock for filtered tailings.

The assessment outcome for deposition of thickened tailings was that either option would be acceptable, however subaqueous deposition was preferred principally because it rated higher on the operability and operating costs criteria and was assessed that Traditional Owners would have a distinct visual preference for tailings covered by water rather than an exposed tailings surface. Subsequently, initial BPT workshop consolidation modelling demonstrated that subaerial deposition would provide an advantage over sub aqueous deposition. Since both options were determined to be BPT, the method was changed without the need for an additional assessment.

With filtration of tailings being retained as an option, the deposition of tailings needed to be considered. Two options were considered: dry stacking, and co-disposal with waste rock. Co-disposal of filter cake and waste rock led to higher maximum elevation of tailings in Pit 3, giving preference to dry stacking. There were, however, concerns expressed about the degree to which either technique had a proven track record, and it was noted that both would be sensitive to rainfall (a dry pit would be required).

The conclusions arising from the BPT workshop on tailings management were:

[1] The initial BPT workshop was conducted prior to the groundwater solute transport modelling from Pit 3; this option was assessed in case treatment of tailings was required in order to achieve the 10,000 year requirement for no detrimental environmental impact. Subsequent to this BPT assessment modelling has shown that additional tailings treatment is not required to mitigate solute transport.

- dredging is the preferred tailings reclamation method;
- cementation is not currently considered viable as a treatment method; and
- tailings filtration should be retained as a potential treatment method to be considered in the overall strategic workshops but is a very expensive option that produces little benefit.

6.5.2 Integrated tailings, water and closure – PFS 2

The combination of the feasible tailings management options and the feasible salt management options resulting from PFS1 and the BPT assessment are provided below:

- dredged tailings, thickened and pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill)
- dredged tailings, thickened, filtered, then pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill)
- dredged tailings, thickened then pumped to Pit 3 combined with crystallisation of brine to be placed within Pit 3
- dredged tailings, thickened, filtered, then pumped to Pit 3 combined with crystallisation of brine to be placed within Pit 3

These options progressed through ITWC PFS2 and were assembled into closure strategies where the preferred technical options from PFS1 were combined with two possible processing cessation dates:

- milling will cease in 2016 - these options were given a 'C' designation; or
- milling will cease at the end of 2020 consistent with the terms of the Ranger Authorisation - these options were given a 'B' designation.

This provided a total of eight closure strategies that were assessed in two stages; these are shown in Table A6.1-5 (and the ranking matrices at the end of Section 6.5).

Table A6.1.5: Initial closure strategies to be assessed

Strategy	Brine strategy	Tailings strategy	Milling end
1C	Injection	Thickened	2016
2C	Injection	Thickened and filtered	2016
3C	Crystallisation	Thickened	2016
4C	Crystallisation	Thickened and filtered	2016
1B	Injection	Thickened	2020
2B	Injection	Thickened and filtered	2020
3B	Crystallisation	Thickened	2020
4B	Crystallisation	Thickened and filtered	2020

Stage 1 assessment

The BPT assessment of the eight identified strategies was divided into two stages. Stage 1, or the preliminary strategic assessment, was conducted soon after completion of the individual component assessments. The intention was to eliminate strategic options that clearly did not constitute BPT, and to more clearly identify information gaps in the remaining options needing to be addressed prior to the final BPT assessment of the strategic options.

The key options that were eliminated in the stage 1 assessment were tailings filtration and brine crystallisation. The results of the stage 1 assessment are shown in Figure A6.1-3.

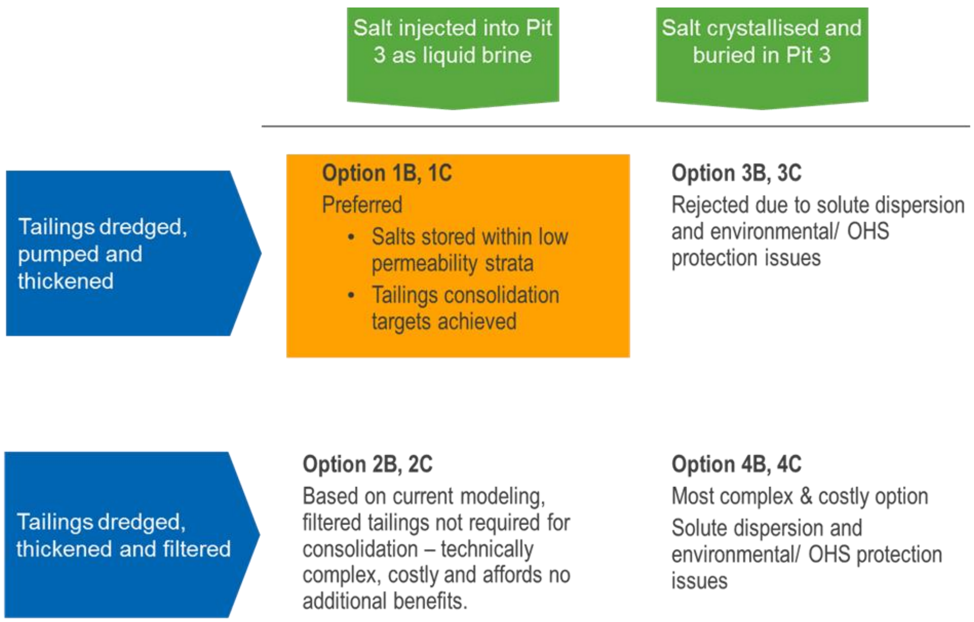

Figure A6.1.3: Outcomes of the stage 1 assessment

The tailings management workshop confirmed filtration was a very expensive option with limited advantages and therefore it was decided that filtration of tailings (2C, 2B) should not be considered further in the development of the best practice strategy for rehabilitation and closure of the Ranger Mine.

Further analysis and test work completed following the initial technical options BPT workshops confirmed brine injection was the best option for management of salt. Further to this, the Stage 1 BPT confirmed brine crystallisation was not a viable option, performing poorly under several criteria. As a result, the strategies that included crystallisation (3B, 3C, 4B, 4C) of the brine stream from the water treatment plant were rejected.

Stage 2 assessment

Based on the Stage 1 BPT assessment, all filtration and crystallisation options were eliminated (this was further validated by programs conducted between the stage 1 BPT and the stage 2 BPT). As such, the closure strategies considered in the Stage 2 BPT workshop were limited to 1B and 1C, however, extended water treatment cases (5B and 5C) were considered as well. This was to allow for the scenario where process water volumes exceed the BC treatment capacity, allowing for longer term treatment of process water.

Table A6.1. Table A6.1-6 lists the options assessed in Stage 2 (detailed ranking matrices at the end of Section 6.5).

Table A6.1.6: Final closure strategies assessed

Strategy	Brief description
1C	Brine injection, thickened tailings, milling until 2016
1B	Brine injection, thickened tailings, milling until 2020
5C	Strategy 1C with extended water treatment
5B	Strategy 1B with extended water treatment

The highest BPT score of 19 was recorded for Strategy 1B; the three other options scored 15. To put this result in perspective, changing the assessed score for any individual criterion by one unit would change the overall score for that option by about two units. Hence, these results imply that option 1B is the favoured option based on the BPT assessment process, but the result is marginal.

The criteria where differences were recorded were:

- socio-economic impact on Jabiru and the region: the two extended options provide additional time for community partnerships to run and continued retention of services, the 5B case also provides additional royalty income;
- technical performance: both 2020 options scored higher because the extended milling period enables the processing of lower grade ores, previously assessed as not commercially viable;
- capital expenditure: the two extended options scored higher primarily because only one BC is required for these options;
- maintainability: the 2020 milling option with extended water treatment results in the use of the BC for nine years beyond its planned lifetime;
- operating costs: the operating costs of the extended 2020 option would be higher because replacement of major BC parts would almost certainly be required; and
- schedule: both extended options scored lower than the primary options under the schedule criterion.

6.5.3 Supplementary integrated tailings, water and closure prefeasibility study

A review of the ITWC BPT assessment was conducted in August 2016. This determined, with the exception of tailings treatment, all technical options selected as BPT remained valid.

Eight options were assessed using the same assessment criteria, scoring and weighting, as used in the ITWC PFS assessment. The results are presented in Table A6.1-7 and the ranking matrices provided at the end of Section 6.5. Of the eight options assessed, one hard show-stopper and four soft show-stoppers were identified by workshop participants.

Table A6.1.7: Supplementary tailings treatment assessment

Strategy	Technology	Show-stopper		Overall rank
		Hard	Soft	
A1	Thickened tailings (ITWC base case)			32.6
A2	Unthickened tailings	✓		-100
A3	Unthickened tailings, with prefabricated vertical drains (wicks)			41.3
A4	Unthickened tailings, with extended water treatment		✓	-6.5
A5	Unthickened tailings, with inline agglomeration and wicks			10.9
A6	Unthickened tailings with neutralisation and wicks		✓	17.5
A7	Thickened and filtered tailings (ITWC assessed)		✓	13.0
A8	Thickened, filtered and cemented tailings (ITWC assessed)		✓	6.8

For most of the detailed options assessed, a NA (not applicable) result was obtained for criteria in the 'Culture and Heritage', and 'Ecosystems and Natural World Heritage Values of Kakadu NP' categories. All activities associated with all options occur within the cultural heritage exemption zone. In addition, these methods do not have any impact on the surrounding ecosystems and World Heritage values of Kakadu during the operational phase. Hence, the BPT assessment of the tailings treatment options was dominated by the criteria under the 'Fit for Purpose', 'Operational Adequacy' and 'Constructability' categories.

The base case for this assessment assumed tailings would be unthickened, with three options being considered a) with wicks, b) with extended water treatment, and c) with inline agglomeration and wicks. These were assessed against the previous ITWC thickened tailings options.

The results of the BPT indicate that unthickened tailings with wicks (A3) have advantages over unthickened tailings and extended water treatment (A4) and unthickened tailings with inline agglomeration (A6). It was assessed that the use of wicks would be viewed more favourably by Traditional Owners under the 'Living Culture' criterion compared to unthickened (A2). The unthickened tailings option (A2) was hard show-stopped due to factors including: not all process water being removed during consolidation, subsidence and erosion of the landform, impacts on rehabilitation performance, impacts to water quality and the formation of visible salts in the landform surface, all of which could lead to an unwillingness for Traditional Owners to resume cultural practices on the site post-closure.

Unthickened tailings with wicks (A3) have been demonstrated as proven technology through its application in Pit 1. Prefabricated vertical drains, or wicks, present a sound technical method of achieving increased consolidation and ensuring the schedule requirements on rehabilitation on the RPA are met.

Inline agglomeration and wicks (A5) option faired less favourably across ‘Fit for Purpose’ and ‘Operational Adequacy’ categories than options A1 and A3, predominantly based on less certainty around achieving consolidation targets and potential reliability issues related to inconsistent input densities. There was also a high uncertainty around the complexity of integration with existing dredging operations, high operational expenditure and complexities associated with construction of the plant on the pit access ramp.

Unthickened with extended water treatment (A4) was soft show-stopped under category ‘Construction, Environmental and Cultural risks’ because of the increased number of vehicles through Kakadu NP necessary to transport new infrastructure and the substantial increase in workforce required to construct a new water treatment plant. It emerged as the least favoured option, scoring ‘inadequate to ‘poor’ against most categories under ‘Fit for Purpose’, ‘Operational Adequacy’ and ‘Constructability’. The low ranking against these criteria was strongly influenced by high sustaining capital and operating costs associated with the existing BC, long procurement lead times required to purchase a new plant or additional infrastructure to expand the existing plant, and the complex operational nature of the plant potentially leading to a high number of interruptions and downtime.

Strategies A6 through A8 all recorded soft show-stoppers under ‘Construction’, ‘Environmental’ and ‘Cultural’ risks criterion, attributed to the effects of increased traffic volumes through Kakadu NP associated with new infrastructure and increased construction workforce in Jabiru. These options also recorded soft show-stoppers under OHS, attributed to increased risks of vehicle incidents during tailings transfer to Pit 3. In addition to the above, concerns identified during the ITWC PFS around strategy A8 (thickened, filtered and cemented) remain. These include the extremely high operational costs as a result of high cement consumption and uncertainty around the long-term stability of cement, which is susceptible to sulfate attack. Significantly more development work would be required before this would be considered a viable option when compared to strategies that were assessed.

Conclusions

The BPT assessment has considered viable thickened tailings options from the previous ITWC PFS and new, unthickened tailings treatments. Of the eight options assessed, one option was hard show-stopped (unthickened A2) and four were soft show-stopped.

Three options were considered viable; however inline agglomeration with wicks (A5) scored the lowest of the three with the assessment identifying some inherent issues around achieving consolidation targets, high operational costs and construction complexities, compared to the other two options (e.g. thickened and unthickened with wicks).

There was no material difference in the assessment scores for the thickened (A1) and unthickened with wicks (A3) options. However, ERA has extensive knowledge around strategy A3, based on the performance of the Pit 1 backfill strategy and subsequent tailings consolidation being achieved via this method.

6.6 Tailings deposition into Pit 3 for mill tailings and dredge tailings

Report: *Application Pit 3 Tailings Deposition, 2019*

In preparation for cessation of mining and processing activities at Ranger Mine, a further assessment of the methods for tailings deposition was undertaken. An application was submitted to the Director of Mining Operations, DPIR (now DITT) in March 2019 to change the deposition method of tailings in Pit 3 from subaerial (to a tailings beach) to subaqueous (into water) (ERA, Alan Irving & Associates 2019). The application was approved in July 2019. The change was proposed to improve deposition, specifically to:

- prevent segregation;
- prevent accumulation of fine tailings in inundated areas of the pit; and
- accelerate backfilling with consolidated tailings.

Following detailed assessment of various subaqueous deposition configurations and multi-spigot subaerial deposition options for Pit 3, a BPT assessment was undertaken in January 2019 to assess the range of potentially viable deposition options (GHD 2019). To conduct this assessment, tailings under consideration were separated into either mill tailings or dredge tailings and scored against the six major criteria. This resulted in an overall ranking calculated for each option (Table A6.1-8 and the ranking matrices at the end of this sub-section).

Table A6.1-8 Tailings deposition options and best practicable technology assessment summary

Option	Option Description	Overall Rank
Mill Tailings		
M1	Subaerial deposition from the current, multiple discharge points (one at a time, infrequently changing)	41.7
M2	Subaerial deposition from multiple spigots on the east wall (one at a time, frequently changing)	35.4
M3	Subaqueous deposition	16.7

Dredge Tailings		
D1	Dredge 1 and 2 subaerial	20.8
D2	Dredge 1 and 2 subaqueous	16.7
D3	Dredge 1 subaqueous & Dredge 2 subaerial	12.5
D4	Dredge 1 subaerial & Dredge 2 subaqueous	10.4

The BPT assessment found that for mill tailings, the two subaerial options (M1 and M2) were similarly effective, and slightly better, than subaqueous discharge (M3) due to the higher cost and greater complexity of subaqueous deposition. Option M2 has the advantage of maintaining a lower, more level tailings surface. Both M1 and M2 promote overall drainage from east to west and are more cost effective than subaqueous deposition. However, M1 scored lower on schedule and both M1 and M2 will result in a slightly higher tailings level in the east of the pit.

The assessment found that for dredge tailings, the subaerial options scored more favourably on costs, constructability, operability and maintainability criteria. This is primarily due to the lower complexity of the subaerial method and because most of the subaerial facilities are already in place. However, the subaerial options scored poorly on schedule and technical performance, as the tailings surface will be more steeply sloping with a higher maximum elevation in the pit requiring additional work to even out the tailings prior to commencement of pit capping.

Conversely, the subaqueous option scored more favourably on schedule, technical performance and environmental protection, since this method promotes less tailings segregation and more rapid consolidation, and the tailings surface will be flatter with a lower maximum elevation in the pit.

Whilst relative advantages and disadvantages were identified, and all options were considered acceptable against each of the assessment criteria, a combination of options M2 (subaerial deposition from multiple spigots on the east wall) and D2 (dredge 1 and 2 subaqueous) was selected.

BPT FINAL ASSESSMENT		Rank	Inadequate 1	Poor 2	Acceptable 3	Good 4	Excellent 5	Unable to evaluate UTE	Not applicable to this option NA
ITWC Project				TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting		Yes	Yes	Yes	No	Yes	No
			Rank weighting	1	1	1	1	1	1
Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Town/Region	Ecosystems of Kakadu	Ecosystems of Project Area
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	0	1	15	3	3	4	3	4	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	0	1	15	3	3	4	3	4	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	0	1	19	3	3	4	4	4	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	0	1	15	3	3	4	4	4	3

BPT FINAL ASSESSMENT	Inadequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to this option			
	1	2	3	4	5	UTE	NA			
ITWC Project	Fit for Purpose					Operational Adequacy				
	No	No		Yes	No	Yes	No	No	No	No
	1	1	1	1	1	1	1	1	1	1
Option Description	Proven technology	Technical performance	Robustness	Environmental Protection	CAPEX	Safety Occupational Health	Operability	Inherent availability and reliability	Maintainability	OPEX
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	4	4	3	4	3	3	4	4	3	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	4	4	3	4	4	3	4	4	3	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	4	5	3	4	3	3	4	4	3	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	4	5	3	4	4	3	4	4	2	2

BPT FINAL ASSESSMENT	Inadequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to this option		
	1	2	3	4	5	UTE	NA		
ITWC Project	Rehabilitation and Closure						Constructability		
	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
	1	1	1	1	1	1	1	1	1
Option Description	Revegetation	Radiation	Erosion	Water Quality	Tailings	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction Complexity
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	4	3	3	UTE	2	2	3	4	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	4	3	3	UTE	2	1	3	4	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	4	3	3	UTE	2	2	3	4	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	4	3	3	UTE	2	1	3	4	3

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

					TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu National Park	Ecosystems of the Project Area
A1	Thickened (ITWC base case)	0	0	32.6	4	NA	4	3	NA	3
A2	Unthickened	4	0	-100.0	1					
A3	Unthickened - wicks	0	0	41.3	3	NA	4	3	NA	4
A4	Unthickened - extended water treatment	0	1	-6.5	3	NA	4	3	NA	3
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	3	NA	4	3	NA	3
A6	Unthickened - neutralisation and wicks	0	2	17.5	UTE	NA	4	4	NA	3
A7	Thickened & filtered tailings	0	3	13.0	4	NA	4	3	NA	2
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	NA	4	3	NA	2

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

		Show stopper column setting			Fit for Purpose					Operational Adequacy				
					No	No	No	Yes	No	Yes	No	No	No	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX	Occupational Health & Safety	Operability	Inherent availability and reliability	Maintainability	OPEX
A1	Thickened (ITWC base case)	0	0	32.6	5	4	3	4	2	4	4	4	4	3
A2	Unthickened	4	0	-100.0		1								
A3	Unthickened - wicks	0	0	41.3	5	3	2	4	3	4	5	5	5	5
A4	Unthickened - extended water treatment	0	1	-6.5	5	2	2	4	1	4	1	2	2	1
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	3	3	2	4	3	4	3	3	3	3
A6	Unthickened - neutralisation and wicks	0	2	17.5	5	UTE	2	4	2	2	4	4	4	1
A7	Thickened & filtered tailings	0	3	13.0	5	4	3	4	1	2	3	3	3	2
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	UTE	3	5	1	2	3	3	2	1

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

		Show stopper column setting			Rehabilitation and Closure						Constructability		
					Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
A1	Thickened (ITWC base case)	0	0	32.6	4	4	3	4	4	3	4	3	4
A2	Unthickened	4	0	-100.0	1		1	1					
A3	Unthickened - wicks	0	0	41.3	4	4	3	4	4	3	3	4	4
A4	Unthickened - extended water treatment	0	1	-6.5	4	4	3	4	4	2	4	2	2
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	4	4	3	4	4	3	3	3	2
A6	Unthickened - neutralisation and wicks	0	2	17.5	4	4	3	4	4	3	4	2	UTE
A7	Thickened & filtered tailings	0	3	13.0	4	4	3	4	4	4	4	2	3
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	4	3	4	4	4	4	2	3

						Traditional Owner Culture & Heritage		Protection of People and the Environment			
			Showstopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Ecosystems & the natural world heritage values of Kakadu	Ecosystems of the project area	Community Health and Safety	Socio-economic Impact on Local Communities	Ecosystems & natural world heritage values of Kakadu	Ecosystems of the Project Area
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time – infrequent switching between two locations (current scenario)	0	0	41.7	4	3	3	3	4	3
No	M2	Sub-aerial, discharge from a single point at a time – frequent switching between multiple locations (spigots)	0	0	35.4	4	3	3	3	4	3
No	M3	Sub-aqueous	0	0	16.7	4	3	3	3	4	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	3	3	3	3	4	3
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	4	3	3	3	4	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	3	3	3	4	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	3	3	3	4	3

Best Practicable Technology Matrix continued...						Fit for Purpose					Operational Adequacy
			Showstopper column setting			No	No	No	Yes	No	Yes
Initial Showstopper	Option #	Option Description	Showstopper 1 indicator	Showstopper 2 indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental protection	CAPEX	Occupational health & safety
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	5	4	3	3	5	4
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	5	4	3	3	4	4
No	M3	Sub-aqueous	0	0	16.7	5	3	4	4	2	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	5	2	3	3	4	4
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	5	4	5	4	2	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	5	3	4	3	4	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	5	3	4	3	3	3

Best Practicable Technology Matrix continued...						Operational Adequacy				Rehabilitation and Closure	
			Showstopper column setting			No	No	No	No	Yes	Yes
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Operability	Inherent availability & reliability	Maintainability	OPEX	Revegetation (closure only)	Radiation (closure only)
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	5	5	5	5	3	3
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	4	5	4	4	3	3
No	M3	Sub-aqueous	0	0	16.7	3	4	3	2	3	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	5	3	4	4	3	3
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	2	3	3	2	3	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	3	3	3	3	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	3	3	3	3	3

Best Practicable Technology Matrix continued...						Rehabilitation and Closure				Constructability		
			Showstopper column setting			Yes	Yes	Yes	No	Yes	Yes	No
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Erosion (closure only)	Water (closure only)	Tailings (closure only)	Schedule	Construction occupational health & safety	Construction environmental and cultural risks	Construction complexity
Mill Deposition												
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	3	NA	4	2	4	5	4
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	3	NA	4	3	4	5	4
No	M3	Sub-aqueous	0	0	16.7	3	NA	4	3	3	5	3
Dredge Deposition												
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	3	NA	3	1	4	5	4
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	3	NA	4	3	3	5	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	NA	3	2	3	5	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	NA	3	2	3	5	3

6.7 Remnant tailings transfer

The bulk of the tailings within the Tailings Storage Facility (TSF) was dredged and transferred into Pit 3 in 2020/2021. Remnant tailings, the material that remained on the TSF floor and walls after the bulk tailings transfer, also needed to be encapsulated in Pit 3 as per the ERs. This BPT investigated 10 options to determine the best method to undertake this activity.

A BPT workshop was conducted in February 2021 to assess the range of potentially viable transfer options. Each option was assessed against the relevant criteria and the resulting scores are shown in Table 6.1-9.

Table 6.1-9: BPT Overall ranking for HDS recommissioning and release

Option	Option description	Score
1	Pre-Cap Pump (base case)	2
2	Post-Cap Truck (Pit 3 west end)	6
2a	Post-Cap Truck (Pit 3 east end)	0
2b	Post-Cap Truck (temp store in Pit 3 THWS rather than TSF SE temp cell)	-6
3	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall, tailings slurried to push lower into pit)	17
3a	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall)	6
3a (i)	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall)	4
3b	Pre-Cap Truck, sucker truck ramp to north wall (below cap)	2
3c	Pre-Cap Truck, Pit 3 west ramp, barge or floating conveyor transfer to west central end of pit	0
4	Bury tailings in TSF	Hard show-stopped

Option 3 was selected as the preferred method for the transfer of remnant tailings, having the highest score of 17. Each individual criteria ranked for Option 3 received as '3' or greater, indicating that the selected approach meets or exceeds current standards across all assessed fields.

The remnant tailings transfer commenced in Q2 2021, following construction of the Pit 3 tip head and upgrades to the required haul roads. Some of the remnant tailings have 'hung up' on the internal wall of Pit 3 and the most effective method to move these tailings deeper into the pit is the subject of current assessment.

6.8 High Density Sludge plant recommissioning

Report: *Application to release water from the High Density Sludge (HDS) Plant, 2020*

The HDS plant was recommissioned on a trial basis in 2019 with the HDS product water recycled into the process water inventory. The recommissioning of the HDS plant was a planned strategy to increase the capacity of process water treatment during closure. An application was submitted to the Director of Mining Operations, DPIR (now DITT) in January 2020 to approve the release of HDS treated process water generated from the recommissioned plant by either of the following options:

- Direct treatment through Water Treatment Plant 1 (WTP1) and subsequent release to the Corridor Creek Wetland Filter;
- Indirect treatment by releasing HDS product into the pond water inventory, for subsequent treatment through any of the pond water treatment plants (WTPs).

Approval was granted in February 2020 with specification for discharge of water to RP2 when releasing HDS product water via indirect treatment as per the application. This approval was contingent on ERA implementing operational controls described in the revised application.

To support this application a BPT assessment was conducted to build upon the previous BPT analysis that was completed to support the original construction of the HDS plant in 2004. The recent BPT assessment evaluated twelve (12) options to address additional process water treatment capacity. The majority of options scored high (31 – 44.4) and differed marginally in the weighting of individual criteria namely ‘Robustness’, ‘Cost’, ‘Schedule’ and ‘Construction complexity’ (Table A6.1-10 and the ranking matrices at the end of this section).

Table A6.1.10: BPT Overall ranking for HDS recommissioning and release

Option	Option description	Score
5.1	Recommission the existing HDS plant, full treatment and transfer of product water direct to WTP1 (dry season only).	31.0
5.2	Recommission the existing HDS plant, full treatment and transfer product water direct to pond water inventory (year round).	33.3
5.3	Recommission the existing HDS plant, adaptive operation (full treatment) with product transfer to either WTP1 (dry season) or pond water storage (year round).	33.3
5.4	Recommission the existing HDS plant, partial treatment and transfer product water direct to WTP1 (year round).	31.0
6.1	Repurpose of mill infrastructure for large scale HDS treatment.	16.7
6.2	New build of larger HDS plant for large scale HDS treatment.	16.7
7.1	BC single train equivalent construction.	35.7
7.2	BC duplication construction.	33.3
8.1	Direct feed process water (untreated) to existing UF/RO infrastructure.	40.5
8.2	Direct feed process water (untreated) to new UF/RO infrastructure similar to current.	33.3
8.3	Discharge process water (untreated) direct to pond water inventory (untreated).	38.1
11	Do nothing.	44.4

All options exceeded current standards for environmental protection and proven technology. The options that ranked highest overall (38.1 – 44.4) were assessed as not feasible for current implementation on the basis that they did not align with the overarching objectives, required significantly high capital expenditure ($10M+), or would likely cause impacts to the closure schedule (i.e. construction delays or conflicts with other closure commitments).

The option identified as most suitable for implementation involved the use of the existing HDS plant under adaptive operational conditions to optimise treatment capability (option 5.3). This option received the mean overall ranking (33.3) and represents a rational approach to addressing project limitations whilst maintaining effective environmental outcomes.

					TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting				Yes	Yes	No	Yes	Yes
Option ID	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local	Ecosystems & Natural world heritage	Ecosystems of the Project Area
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	3	4	4	3	4	4
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	3	4	4	3	4	4
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	3	4	4	3	4	4
5.4	Recommission the existing HDS plant, partial treatment			31.0	3	4	4	3	4	4
6.1	Re-purpose mill infrastructure			16.7	3	4	3	3	4	4
6.2	New build HDS plant			16.7	3	4	3	3	4	4
7.1	BC single train equivalent			35.7	3	4	4	3	5	5
7.2	BC duplication			33.3	3	4	4	3	5	5
8.1	Direct feed to existing UF/RO infrastructure			40.5	3	4	4	3	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	3	4	4	3	4	4
8.3	Discharge direct to pond inventory			38.1	3	4	4	3	4	4
11	Do nothing			44.4	3	4	4	3	5	5

					Fit for Purpose					Operational Adequacy				
		Show stopper column setting			No	No		Yes	No	Yes	No	No	No	No
Option ID	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX	Occupational Health & Safety	Operability	Inherent availability and reliability	Maintainability	OPEX
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	4	4	3	4	4	4	3	3	3	3
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	4	4	3	4	4	4	3	4	3	3
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	4	4	3	4	4	4	3	4	3	3
5.4	Recommission the existing HDS plant, partial treatment			31.0	4	4	3	4	4	4	3	3	3	3
6.1	Re-purpose mill infrastructure			16.7	4	4	4	4	3	4	3	4	3	3
6.2	New build HDS plant			16.7	4	4	5	4	2	4	3	4	3	3
7.1	BC single train equivalent			35.7	4	5	4	5	2	4	4	4	4	3
7.2	BC duplication			33.3	4	5	5	5	1	4	4	4	4	3
8.1	Direct feed to existing UF/RO infrastructure			40.5	4	3	3	4	5	4	4	4	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	4	3	4	4	2	4	4	4	4	4
8.3	Discharge direct to pond inventory			38.1	4	3	2	4	5	4	4	4	4	4
11	Do nothing			44.4	5	4	1	4	5	4	NA	NA	NA	3

					Rehabilitation and Closure						Constructability		
		Show stopper column setting			Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Option ID	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	NA	NA	NA	4	NA	3	4	4	4
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	NA	NA	NA	4	NA	3	4	4	4
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	NA	NA	NA	4	NA	3	4	4	4
5.4	Recommission the existing HDS plant, partial treatment			31.0	NA	NA	NA	4	NA	3	4	4	4
6.1	Re-purpose mill infrastructure			16.7	NA	NA	NA	3	NA	2	3	3	2
6.2	New build HDS plant			16.7	NA	NA	NA	3	NA	2	3	3	2
7.1	BC single train equivalent			35.7	NA	NA	NA	4	NA	3	3	3	2
7.2	BC duplication			33.3	NA	NA	NA	4	NA	2	3	3	2
8.1	Direct feed to existing UF/RO infrastructure			40.5	NA	NA	NA	4	NA	3	4	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	NA	NA	NA	4	NA	3	4	4	3
8.3	Discharge direct to pond inventory			38.1	NA	NA	NA	4	NA	3	4	4	4
11	Do nothing			44.4	NA	NA	NA	4	NA	1	5	5	5

6.9 TSF North Notch Stage 3

Report: *Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility North Notch Stage 3, 2020*

The water level of the TSF continued to be lowered to maximise the efficiency of the dredges during the transfer of tailings to Pit 3. As a result of the lowering water level, there was a need to create notches within the TSF walls to increase the pumping efficiency and to maintain safe access to the floating infrastructure. An application was submitted to the Director of Mining Operations, Department of Primary Industry and Resources (DPIR) (now Department of Industry, Tourism and Trade [DITT]) in April 2020 to approve reduction of the clay core crest height to Relative Level (RL) 37.8 m and to manage future raises in crest height with the construction of clay bunds across the notch if required. The DPIR (now DITT) approved the application in June 2020 and agreed to the provision of water balance modelling updates of the inventory at the beginning of each dry season to ensure sufficient capacity for the upcoming wet season.

Notching the TSF wall proved to be fit for purpose and environmentally sound for the construction of the previous three notches. The construction of a further notch within the footprint of the North wall notch did not require a BPT assessment. However, the reduction in crest height to a level that enabled the completion of dredging presented a risk of inadequate water storage volume when considering the future needs of the TSF for process water storage facility. The purpose of this BPT assessment was to identify the most environmentally sound approach for ongoing safe access to the TSF during dredging whilst ensuring adequate crest height to meet the freeboard requirements of the Ranger Authorisation until 2024.

A total of six options were assessed as part of the BPT assessment (Table A6.1-11 and the ranking matrices at the end of the section).

Table A6.1-11 BPT options assessment for TSF notch

Option	Option Description	Overall Rank
A1	Construct North Notch 3 to RL 36. (clay core RL 35.8 m) & construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0
A2	Construct North Notch 3 to RL 37.3 m (clay core RL 36.8 m) & construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0
A3	Construct North Notch 3 to RL 36.3 m RL. Infill the notch to Stage 2 level following completion of TSF cleaning operation.	0
A4	No additional notch. 1.1 Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services and gantry into a local cutting. Crane used from Notch 2 for large lifts.	-2.8
-A5	Continue use of North Notch 2 using large crane and modified gantry.	Hard show-stopper

A6	North-East Ramp. Remove current ramp in North-East corner of TSF. Cut in new ramp, beginning from further back, in stockpile area, and notching down into TSF wall to RL36.3m. Creates notch in North-East corner. Access as per A1.	-19.4

Most of the options received scores close to zero, indicating that they meet industry standard. No option was considered to substantially exceed industry standard. This is expected given the unfamiliar activity of removing tailings from a tailings storage facility. The continued use of North Notch 2, requiring a modified gantry and an estimated 600 – 700 tonne crane for ongoing access to the lift workboats, was hard show-stopped at the beginning of the assessment. Gantry modification to the extent required to meet safety requirements was considered to be prohibitively expensive.

Option A2, the construction of a third notch in the North wall to a height of RL 37.3 m, was determined to be the most suitable approach. This option includes the contingency to construct a clay bund within the notch if it is required to ensure adequate freeboard during the wet seasons. It is assumed that Pit 3 remains available to receive process water from the TSF during extreme weather events to minimise the risk of overflow into the notch.

Although options A1 and A3 received the same final overall ranking, option A2, with the higher notch level, has a lower capital expenditure and construction time than A1 and A2. Capital expenditure and construction time includes clay bund and notch infill. There is a risk of overtopping the notch resulting in seepage into the dam walls in option A2. This risk is removed with the infill of the notch as proposed in option A3. Proposed risk mitigation measures, such as the construction of a clay bund and the cessation of tailings pore water transfer from Pit 3 reduce this risk to an acceptable level and justified the selection of option A2 over option A3.

Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Community health & safety	Socio-economic impact on local communities	Ecosystems & Natural world heritage values of Kakadu National Park	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX
						Protection of People and the Environment			**Fit for Purpose**				
			Show stopper column setting			Yes	No	Yes	No	No		Yes	No
	A1	Construct North Notch 3 to RL36.3m & construct clay bund if required.	0	0	-3.1			3	3	3	2	3	3
	A2	Construct North Notch 3 to RL37.3m & construct clay bund if required.	0	0	-3.1			3	3	2	2	4	4
	A3	Construct North Notch 3 to RL36.3m. Infill the notch again to Stage 2 height after the TSF cleaning operation.	0	0	-3.1			3	3	3	3	4	1
	A4	Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services & gantry into cutting. Use crane for large lifts.	0	0	-15.6			3	2	2	3	3	3
Yes	A5	Continued use of North Notch Stage 2 with large crane and modified gantry			0.0								
	A6	NE Ramp & notch - cut in new ramp from the stockpile area, notch down to RL36.3m.	0	0	-18.8			3	2	3	2	1	1

						Operational Adequacy					Rehabilitation and Closure		Constructability		
			Show stopper column setting			Yes	No	No	No	No	No	No	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Occupational Health & Safety	Operability	Inherant availability & reliability	Maintainability	OPEX	Cost (Operations only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	A1	Construct North Notch 3 to RL36.3m & construct clay bund if required.	0	0	-3.1	3	3	3	3	3	3	3	3	3	3
	A2	Construct North Notch 3 to RL37.3m & construct clay bund if required.	0	0	-3.1	3	2	3	3	3	3	3	3	3	3
	A3	Construct North Notch 3 to RL36.3m. Infill the notch again to Stage 2 height after the TSF cleaning operation.	0	0	-3.1	3	3	3	3	3	3	3	3	3	3
	A4	Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services & gantry into cutting. Use crane for large lifts.	0	0	-15.6	3	2	1	3	4	3	3	3	3	2
Yes	A5	Continued use of North Notch Stage 2 with large crane and modified gantry			0.0										
	A6	NE Ramp & notch - cut in new ramp from the stockpile area, notch down to RL36.3m.	0	0	-18.8	3	3	3	3	3	3	3	3	3	3

6.10 Tailings Storage Facility subfloor material management

Report: *MTC Application Ranger Mine Tailings Storage Facility - Subfloor Material Management, 2020*

ERA undertook an assessment into the viable options for managing the TSF subfloor contaminated material as part of closure planning for the TSF and Pit 3. The assessment was aimed at assessing the environmental impact of leaving the contaminated material *in situ* rather than disposal into Pit 3. The reason for this tightly defined scope was to determine if the planning and application for the closure of Pit 3 was required to consider this subfloor material. The deconstruction of the TSF does not occur until later, and as such, this application was submitted prior to the Pit 3 application and the actual Pit 3 capping works.

Based on the outcomes of the BPT assessment, an application was submitted to the Director of Mining Operations, DITT for approval in March 2020. The application was updated in June 2020 following stakeholder feedback and the DITT approved the application in August 2020.

The BPT assessment involved comparing the option of leaving the contaminated subfloor material *in situ* against a number of methodologies for disposing the material within Pit 3 (Table A6.1-12 and the ranking matrices at the end of this section).

Option 1 was developed as a worst-case scenario for leaving the material *in situ*. Option 2 was omitted from further assessment, to allow for completion of the relevant supporting studies. It is intended that Option 2 will be reviewed on the basis that Option 1 demonstrates a greater 'net environmental benefit' than Option 3 as part of this initial assessment. A total of 12 options were reviewed for disposal of the material within Pit 3.

Table A6.1-12 BPT assessment options and overall ranks for TSF Contaminated Material Management

Option	Option description	Score
1a	Leave material *in situ*. TSF subfloor material left undisturbed *in situ*. All visible tailings removed. TSF is then used for process water storage.	38.2
2	Leave material *in situ*. TSF subfloor material left undisturbed *in situ* with some form of remediation which may use TSF wall material for capping or another methodology.	Initial show-stopper
3a.1	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, stockpiled, with transfer to Pit 3 for use as secondary cap. TSF used for process water storage.	-17.6
3a.2	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, intermediate stockpile, with transfer to Pit 3 for use as primary cap.	Initial show-stopper

Option	Option description	Score
3a.3	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, no stockpile, placed within south-west of Pit 3 as primary cap wedge deposit. TSF used for process water storage.	-35.3
3a.4	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via dredging, not stockpiled, with transfer to Pit 3 for use as primary cap. TSF used for process water storage.	Initial show-stopper
3a.5	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, crush, screen and pump to Pit 3 (above tailings). TSF used for process water storage.	-41.2
3a.6	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, stockpiled, with transfer to Pit 3 and intermixed with mineralised waste rock (co-disposal). TSF used for process water storage.	-23.5
3a.7	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically, stockpiled, with transfer to south-west of Pit 3 as secondary cap wedge deposit. TSF used for process water storage.	-23.5
3b.1	Dispose of material within Pit 3. 20 m of TSF subfloor material removed mechanically, stockpiled, transferred to Pit 3 and use as secondary cap. TSF used for process water storage.	Initial show-stopper
3b.2	Dispose of material within Pit 3. 20 m of TSF subfloor material removed mechanically, stockpiled, partially transferred to Pit 3 and use as secondary cap with remainder to other onsite storage cell. TSF used for process water storage.	Initial show-stopper
3c.7	Dispose of material within Pit 3. 4 m of TSF subfloor material removed mechanically, stockpiled, transferred to Pit 3 and placed in south-west as secondary cap deposit. TSF used for process water storage.	-29.4
3d.6	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically after TSF use as water storage is complete. Schedule optimised.	-29.4
3d.7	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically after TSF use as water storage is complete. Solute optimised.	-29.4

To compare Options 1 and 3, an understanding of the risk of contaminants mobilising into the surrounding environment was necessary to determine how effectively the TSF subfloor could be isolated at each management location. Isolation effectiveness is assessed with regard to the likelihood of contaminants entering groundwater and surface waters, which create solute transport pathways and potentially increase exposure of contaminants to sensitive receptors. The management option that poses the lowest environmental risk and/or avoids having 'a net adverse effect' would be considered the most viable for implementation.

Option 1a (leave *in situ*) ranked highest overall and is the only option with a positive ranking of 38.2. This option scored highest overall for aspects such as 'Environmental Protection', 'Living Culture', 'Cultural Heritage', 'Ecosystems & Natural World Heritage', and 'Tailings', indicating that these aspects meet current standards and are more likely to achieve greater level of environmental and cultural protection than the other management options. This option scored lowest overall for 'Revegetation' (3) and 'Erosion' (2), indicating that this option presents greater risk to final landform management than the Pit 3 transfer options. Overall, this option had the least number of soft show-stopper aspects ('Community Health', 'Radiation' and 'Erosion') in comparison to the other options and was identified as the most viable option for contaminated material management.

						TO Culture & Heritage		Protection of People and the Environment		Fit for Purpose			
			Show stopper column setting			Yes	Yes	Yes	Yes	No	No	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Ecosystems & Natural world heritage values of Kakadu National Park	Proven technology	Robustness (closure only)	Environmental Protection	CAPEX
	Option 1a	TSF subfloor material left undisturbed in situ, post tailings clean includes all visible tailings removed from the TSF floor. Then TSF used for process water storage.	0	3	38.2	3	5	2	3	5	5	4	5
Yes	Option 2	In situ remediation. As per Option 1. then remediated.	0	0	0.0								
	Option 3a.1	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	4	-17.6	2	3	2	2	4	4	3	2
Yes	Option 3a.2	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0								
	Option 3a.3	TSF sub floor material removed to 2 m below composite floor via mechanical removal - no stockpile - move to south west of Pit 3 as primary cap wedge deposit. Then TSF used for process water storage.	0	7	-35.3	2	2	2	2	2	4	3	2
Yes	Option 3a.4	TSF sub floor material removed to 2 m below composite floor via dredging - no stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0								
	Option 3a.5	TSF sub floor material removed to 2 m below composite floor via mechanical removal - crush, screen & pump to Pit 3 (on top of tailings). Then TSF used for process water storage.	1	4	-41.2	2	3	2	1	2	4	3	1
	Option 3a.6	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use by co-disposal with mineralised waste rock. Then TSF used for process water storage.	0	6	-23.5	2	2	2	2	4	4	3	2
	Option 3a.7	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-23.5	2	2	2	2	4	4	3	2

						TO Culture & Heritage		Protection of People and the Environment		Fit for Purpose			
			Show stopper column setting			Yes	Yes	Yes	Yes	No	No	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Environmental Protection	CAPEX	Occupational Health & Safety	Inherent availability and reliability	Revegetation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)
Yes	Option 3b.1	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	0	0.0								
Yes	Option 3b.2	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - partially move to Pit 3 and use as secondary cap with remainder to other onsite storage cell. Then TSF used for process water storage.	0	0	0.0								
	Option 3c.7	TSF sub floor material removed to 4 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-29.4	2	3	2	2	4	4	2	1
	Option 3d.6	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal "" schedule optimised "" Note: ""It means to best maintain the closure schedule, thus the subfloor material would be near the surface of Pit 3 backfill.	0	6	-29.4	2	2	2	2	4	4	3	1
	Option 3d.7	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal "" solute optimised "" Note: ""It means to stop work on Pit 3 backfill until the TSF subfloor material is available to put as low in pit as possible. Thus the closure schedule is exceeded by years.	0	6	-29.4	2	2	2	2	4	4	3	1

						Rehabilitation and Closure						Constructability		
			Show stopper column setting			Yes	Yes	Yes	No	No	No	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	Option 1a	TSF subfloor material left undisturbed in situ, post tailings clean includes all visible tailings removed from the TSF floor. Then TSF used for process water storage.	0	3	38.2	3	2	2	2	3	5	5	5	5
Yes	Option 2	In situ remediation. As per Option 1. then remediated.	0	0	0.0									
	Option 3a.1	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	4	-17.6	4	2	3	1	2	2	3	3	3
Yes	Option 3a.2	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0									
	Option 3a.3	TSF sub floor material removed to 2 m below composite floor via mechanical removal - no stockpile - move to south west of Pit 3 as primary cap wedge deposit. Then TSF used for process water storage.	0	7	-35.3	4	2	3	1	2	2	2	2	2
Yes	Option 3a.4	TSF sub floor material removed to 2 m below composite floor via dredging - no stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0									
	Option 3a.5	TSF sub floor material removed to 2 m below composite floor via mechanical removal - crush, screen & pump to Pit 3 (on top of tailings). Then TSF used for process water storage.	1	4	-41.2	4	2	3	1	1	1	2	3	2
	Option 3a.6	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use by co-disposal with mineralised waste rock. Then TSF used for process water storage.	0	6	-23.5	4	2	3	1	2	2	3	2	3
	Option 3a.7	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-23.5	4	2	3	2	2	2	3	2	2

Energy Resources Of Australia

						Rehabilitation and Closure						Constructability		
			Show stopper column setting			Yes	Yes	Yes	No	No	No	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	0	0	0	0	0	0	0	0	0
Yes	Option 3b.1	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	0	0.0									
Yes	Option 3b.2	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - partially move to Pit 3 and use as secondary cap with remainder to other onsite storage cell. Then TSF used for process water storage.	0	0	0.0									
	Option 3c.7	TSF sub floor material removed to 4 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-29.4	4	2	3	1	2	2	3	2	2
	Option 3d.6	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal "" schedule optimised "" Note: ""It means to best maintain the closure schedule, thus the subfloor material would be near the surface of Pit 3 backfill.	0	6	-29.4	4	2	3	1	2	1	3	2	3
	Option 3d.7	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal "" solute optimised "" Note: ""It means to stop work on Pit 3 backfill until the TSF subfloor material is available to put as low in pit as possible. Thus the closure schedule is exceeded by years.	0	6	-29.4	4	2	3	2	2	1	3	2	2

6.11 Blackjack waste disposal

Report: *Best Practicable Technology (BPT) Assessment Blackjack Waste Disposal, Coffey 2018*

In July 2018, Coffey Services Pty Ltd (Coffey) facilitated a BPT workshop to assess options for the disposal of hydrocarbon waste generated by the Ranger Mine. As part of uranium ore processing, a hydrocarbon lubricant known as blackjack (gear oil), is injected onto the spindle of the ball mill. The inventory forecasted at closure is approximately 72 kL, which equates to approximately 10 (205 L) waste blackjack drums produced annually. There are potential risks associated with blackjack disposal.

Analysis of drummed waste blackjack concluded that the waste at Ranger is contaminated above exemption levels as set out in the National Directory for Radiation Protection (Welman, 2013). Therefore, the waste blackjack cannot be disposed of off-site at a non-radioactive waste facility. The disposal of blackjack is required to be in line with Rio Tinto and ERA policies and standards, and the Ranger ERs. Another risk includes the possibility of light-non-aqueous phase liquids to separate as free product from the blackjack and potentially leak into groundwater. As part of the BPT assessment, each option submitted for review identified and discussed the potential risks associated with the method proposed.

The BPT assessment considered five options for waste disposal including:

- Tellus ‑ National Geological Repository (A1)
    - Transport the blackjack drums in containers via road trains to the selected geological repository (multi-barrier safety case) located at Sandy Ridge (WA) to permanently isolate the waste from the biosphere. The waste will be pre-treated to immobilise contaminants prior to disposal in a bed of low permeability clay.
- Scholer ‑ Diesel fired waste incinerator (A2)
    - Design, manufacture and supply a two-stage waste oil incinerator for consecutive burning of black jack at the Ranger Mine. Overall, the two-stage incineration system ensures complete combustion, eliminating discharge of any toxic incompletely combusted compounds, including potential and actual carcinogenic combustion by-products.
- CDM Smith – Immobilisation & In-cell disposal of contained blackjack in Pit 3 (A3)
    - A proposal was submitted by CDM Smith based on a concept design to include an underground repository during the backfilling of Pit 3. The blackjack waste in this case would be pre-treated and immobilised, retained in a containment structure and buried in a multi-layered barrier system. With regards to pre-treatment, the blackjack waste will be treated physically (solidification process) and chemically (stabilisation process) then be encapsulated within a purpose-built cell in Pit 3 to provide additional layers of containment.

- In-cell disposal of contained blackjack in Pit 3 (A4)
    - Blackjack waste that is currently stored in metal drums will be placed in a containment structure and backfilled in-between waste rock and tailings in Pit 3. This excludes the pre-treatment process and immobilisation as per the CDM Smith A3 option above.
- National radioactive waste management facility (A5)
    - A national radioactive waste management facility was included as part of the original submissions of options however was removed from further consideration before the scheduled BPT assessment, as the proponents were unable to meet the closing date for submissions.

The BPT Assessment determined rankings for each of the five options (Table A6.1-13 and the ranking matrices at the end of this section).

Table A6.1-13 Black jack disposal options and best practicable technology assessment summary

Option	Option description	Score
A1	Tellus – National Geolgoical Repositories	50.0
A2	Scholer – Waste Oil Incinerator	23.8
A3	CDM Smith – Immobilisation and in-cell disposal into Pit 3	-7.1
A4	In-cell disposal into Pit 3	-2.5
A5	National radioactive waste management facility	0.0

Tellus' National Geological Repository (Option A1) received the highest overall score, with 50 points. The second highest was Scholer's Waste Oil Incinerator, scoring 23.8 points. Tellus' National Geological Repository (Sandy Ridge) has received final approval and licencing to accept low-level radioactive waste and is the adopted option.

						TO Culture & Heritage		Protection of People and the Environment				
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes	Yes
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu National Park	Ecosystems of the Project Area	Long term protection of the environment (Operations only)
	A1	Tellus - National Geological Repositories	No	No	50.0	3	3	4	NA	3	5	5
	A2	Scholer - Waste Oil Incinerator	No	Yes	23.8	4	2	3	NA	3	3	5
	A3	Immobillsation and In-cell disposal into pit 3	No	Yes	-7.1	4	4	4	NA	4	4	3
	A4	In-cell disposal into pit 3	No	Yes	-2.5	3	4	4	NA	4	4	1
	A5	**National Radioactive Waste Management Facility	Yes		0.0							

						Fit for Purpose			Operational Adequacy	Rehabilitation and Closure			Constructability		
			Show stopper column setting			No	No	Yes	No	Yes	No	No	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Environmental Protection	OPEX	Environmental Acceptability (Operations only)	Cost (Operations only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	A1	Tellus - National Geological Repositories	No	No	50.0	4	3	4	5	5	5	5	NA	4	NA
	A2	Scholer - Waste Oil Incinerator	No	Yes	23.8	4	4	4	3	3	3	5	3	4	3
	A3	Immobillsation and In-cell disposal into pit 3	No	Yes	-7.1	4	2	2	3	1	3	2	2	4	2
	A4	In-cell disposal into pit 3	No	Yes	-2.5	4	2	1	4	1	3	2	2	4	3
	A5	**National Radioactive Waste Management Facility	Yes		0.0										

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APPENDIX 6.2: BPT ASSESSMENT MATRICES FOR PIT 3 CAPPING

BPT ASSESSMENT RANKING DATABASE

Pit 3 Capping Options

			Show stopper column setting			TO Culture & Heritage		Protection of People and the Environment			
						Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living Culture (Closure)	Cultural Heritage	Community Health & Safety	Socio-Economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu NP	Ecosystems of the Project Area
	A	Sub-Aqueous Capping Method (Base case)	0	1	7	4	4	4	3	4	4
	B	East platform finished with Sub-Aqueous Capping Method	0	1	7	4	4	4	3	4	4
	C.1	Sub-Aerial (passive dry out) Capping Method	0	2	20	3	4	2	4	4	2
	C.2A	Sub-Aerial (accelerated dry out by mechanical assistance) with conventional wicking through bridging layer Capping Method	0	1	9	3	4	3	4	4	3
	C.2C	Sub-Aerial (accelerated dry out by mechanical assistance) with Amphibious wicking through mechanically assisted crust Capping Method	0	1	18	3	4	3	4	4	3
	C.2B	Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method	1	1	16	3	4	3	4	4	3
	D	Hybrid + Eastern Platform	0	1	23	3	4	2	4	4	3

BPT ASSESSMENT RANKING DATABASE

Pit 3 Capping Options

			Show stopper column setting			No	No	No	Yes	No
						Fit for Purpose				
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven Technology	Technical Performance	Sensitivity to external Factors	Environmental Protection	CAPEX
	A	Sub-Aqueous Capping Method (Base case)	0	1	7	2	3	4	4	2
	B	East platform finished with Sub-Aqueous Capping Method	0	1	7	2	3	4	4	2
	C.1	Sub-Aerial (passive dry out) Capping Method	0	2	20	4	5	3	4	4
	C.2A	Sub-Aerial (accelerated dry out by mechanical assistance) with conventional wicking through bridging layer Capping Method	0	1	9	3	3	3	4	3
	C.2C	Sub-Aerial (accelerated dry out by mechanical assistance) with Amphibious wicking through mechanically assisted crust Capping Method	0	1	18	3	5	3	4	3
	C.2B	Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method	1	1	16	3	5	3	4	4
	D	Hybrid + Eastern Platform	0	1	23	4	5	3	4	3

BPT ASSESSMENT RANKING DATABASE
Pit 3 Capping Options

			Show stopper column setting			No	No	No
						Operational / Execution Adequacy		
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Operability/ constructability	Inherent availability, maintainability and reliability	OPEX
	A	Sub-Aqueous Capping Method (Base case)	0	1	7	1	2	4
	B	East platform finished with Sub-Aqueous Capping Method	0	1	7	1	2	4
	C.1	Sub-Aerial (passive dry out) Capping Method	0	2	20	4	4	2
	C.2A	Sub-Aerial (accelerated dry out by mechanical assistance) with conventional wicking through bridging layer Capping Method	0	1	9	3	4	3
	C.2C	Sub-Aerial (accelerated dry out by mechanical assistance) with Amphibious wicking through mechanically assisted crust Capping Method	0	1	18	4	4	3
	C.2B	Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method	1	1	16	4	4	1
	D	Hybrid + Eastern Platform	0	1	23	4	4	4

BPT ASSESSMENT RANKING DATABASE
Pit 3 Capping Options

			Show stopper column setting			Rehabilitation and Closure						Constructability	
						Yes	Yes	Yes	Yes	Yes	No	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation	Radiation	Erosion	Water (Closure Only)	Tailings	Schedule	Construction Occupational Health and Safety	Construction Complexity
	A	Sub-Aqueous Capping Method (Base case)	0	1	7	3	4	3	3	4	3	2	2
	B	East platform finished with Sub-Aqueous Capping Method	0	1	7	3	4	3	3	4	3	2	2
	C.1	Sub-Aerial (passive dry out) Capping Method	0	2	20	3	4	3	3	4	2	4	3
	C.2A	Sub-Aerial (accelerated mechanical assistance) conventional wicking through bridging layer	0	1	9	3	4	3	3	4	2	2	2
	C.2C	Sub-Aerial (mechanical assistance) Amphibious wicking through mechanically assisted crust	0	1	18	3	4	3	3	4	2	2	3
	C.2B	Sub-Aerial (mechanical assistance) no wicking	1	1	16	3	4	3	3	4	2	2	3
	D	Hybrid + Eastern Platform	0	1	23	3	4	3	3	4	2	3	3

APPENDIX 6.3: ALARA

Multiple frameworks informing closure criteria at Ranger mine

M Iles *BMT (Associate), Australia*

Abstract

The Ranger Project Area (RPA), site of Energy Resources of Australia Ltd.'s Ranger mine, is surrounded by (but separate from) Kakadu National Park (KNP) World Heritage Place and Ramsar wetland. Closure requirements differ for on and off the RPA.

The Mirarr Indigenous landowners source food and drinking water up and downstream of the mine and wish to resume these activities on the site after closure. The regulatory Environmental Requirements (ERs) specify that waters and tailings from the mine must not impact the KNP values which includes the local Indigenous culture, health of the local people and the biodiversity and ecological processes of the region. The ERs also state that impacts on the RPA must be as low as reasonably achievable (ALARA). Closure criteria for water and sediment on and off the RPA need to support these diverse values and goals.

The ANZG (2018) WQMF was used to identify indicators to represent KNP values, human health and biodiversity and derive water and sediment quality criteria to support management of these values. Risk and vulnerability assessments were used, at relevant stages in the WQMF, to assess the results of sediment and water quality monitoring and predicted post-closure water quality.

ALARA is widely understood and applied to radiation hazards but not chemical hazards. A fourth framework is required to provide information that will be used to assess if impacts on the RPA are ALARA. This paper demonstrates the role of these frameworks in water and sediment closure criteria development at Ranger mine.

Keywords: *water quality objectives, risk assessment, ecological vulnerability, as low as reasonably achievable (ALARA), closure criteria*

1 Introduction

Energy Resources of Australia Ltd. (ERA) is undertaking closure activities at its Ranger mine, which is surrounded by (but separate to) Kakadu National Park (KNP) World Heritage Place and KNP Ramsar site in the Northern Territory of Australia (Figure 1).

Water at and leaving the mine site following closure has the potential to impact community values on and off the Ranger Project Area (RPA) after closure if not properly managed. High level Environmental Requirements (ERs) for the protection of people and the environment during and after mining at Ranger have been set by the Australian Government (Commonwealth of Australia 2000). Those relevant to water quality specify that:

- Waters leaving the RPA do not compromise the achievement of the primary environmental objectives related to protection of the people, ecosystem (biodiversity and ecological processes), and World Heritage and Ramsar values of the surrounds
- Impacts on the RPA are as low as reasonably achievable (ALARA)
- The strategy for closure of the mine is assessed using a best practicable technology (BPT).

The Mirarr Indigenous landowners source food and drinking water up and downstream of the mine and wish to resume these, and other cultural activities, on the site after closure. In recognition of the importance of waterways on the RPA they requested that in riparian zones and water bodies, the standard of rehabilitation be as high as is technically possible and the level of contamination be as low as technically possible.

Closure criteria for water and sediment on and off the RPA and decision-making processes need to support achieving these diverse values and water management goals. Iles (2019) discussed plans for (i) applying the ANZG (2018) water quality management framework (WQMF) for setting closure criteria at Ranger, and (ii) the role of BPT and understanding ecosystem vulnerability when determining if impacts are ALARA. Stakeholders agreed with the planned approach in principle provided they were involved in decisions on what is reasonable (the R in ALARA), the goal of 'technically possible' was properly considered and it was clear how these different frameworks inform the different management goals on and off the RPA.

This paper describes:

- The holistic framework that is being adopted by ERA to identify closure options that are BPT and most likely to result in impacts on the RPA that are ALARA
- How risk and vulnerability assessments are being applied to understand the impacts associated with water quality
- How the process can inform decisions on 'technically possible' and 'reasonable', and
- How these fit within the WQMF to establish closure criteria and assess compliance with the ERs and community values.

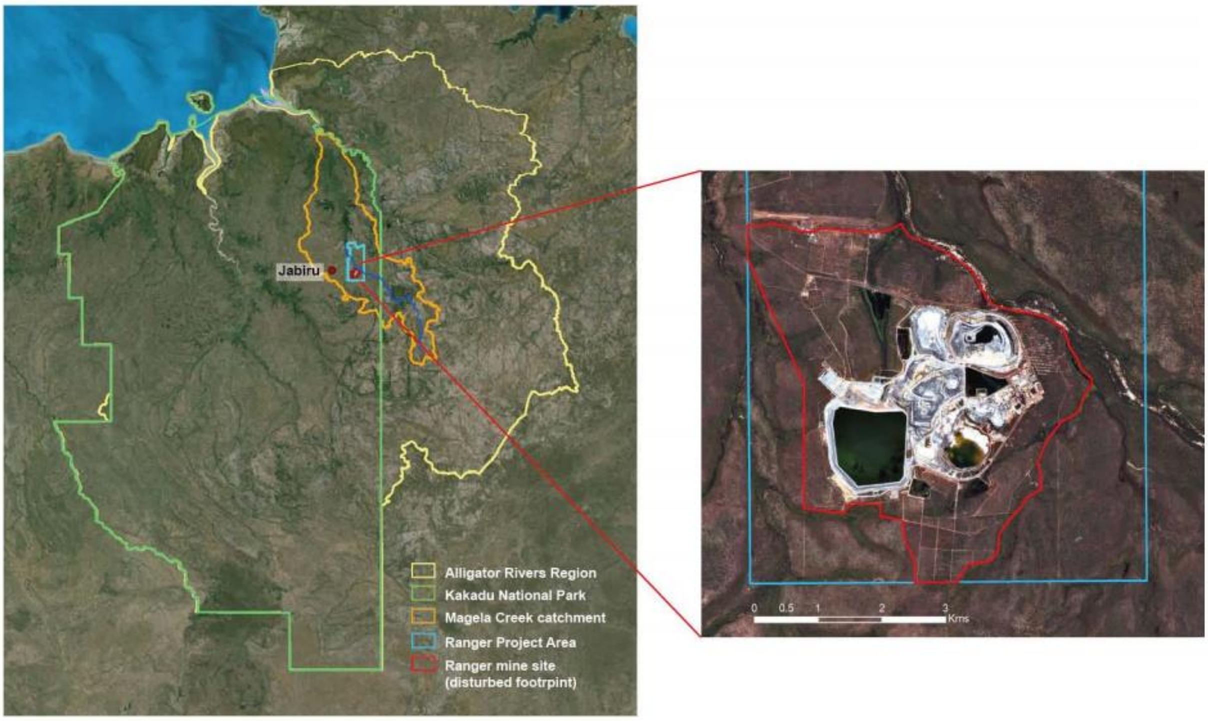

Figure 1 Ranger project area and mine site location

2 Assessment frameworks to support water closure criteria

Multiple assessment approaches are being used to develop closure criteria for the water related management goals for Ranger mine and assess compliance with these. These include the:

- ANZG (2018) WQMF
- Environmental risk assessment framework

- Ecological vulnerability assessment framework (VAF)
- BPT multi-criteria decision analysis framework
- ALARA framework.

These different frameworks have many aspects in common (**Error! Reference source not found.**) and do not stand alone with steps in common creating a web of frameworks (Figure 2)

Error! Reference source not found. Approach for assessing compliance with water quality related Environmental Requirements

Environmental Requirement	Assessment approach	Applicable Framework
Protect the people and biodiversity	Quantitative source-pathway-receptor risk assessment comparing current or predicted water and sediment concentrations to guideline values for species protection, drinking water, recreational water	ANZG 2018 Water quality management framework (WQMF) Environmental risk assessment Ecological vulnerability assessment framework (VAF)
Protect ecological processes, World Heritage and Ramsar values	Identify key indicator species/groups and sensitivity to main contaminant	As above. Indicators for World Heritage and Ramsar values set under the VAF
Impacts to be ALARA on the RPA	Iterative risk, vulnerability and BPT assessments	As above plus ALARA framework
Closure strategy is BPT	Multi-criteria decision analysis	BPT framework (a step within the ALARA framework)

2.1 Water quality management framework

ERA is following the ANZG (2018) WQMF to provide a process for stakeholders to develop agreed water quality objectives that apply both on and off the RPA. The WQMF provides a sequential stepwise approach (central wheel in **Error! Reference source not found.**) to setting management goals through to assessing, refining and deriving water and sediment quality objectives and guideline values. Several of the steps are also common to the VAF and ALARA framework and the environmental risk assessment is embedded both within the WQMF and the ALARA framework. The relationships are illustrated in Figure *2*.

Steps 1 to 5 of the WQMF cover setting objectives for each value being protected and identifying the most stringent of these as draft guideline values. At step 6 whether the objectives/guidelines can be met was tested using a source-pathway-receptor environmental risk assessment (section 2.2.1). This is also part of the ALARA process (section 2.3.2). If exceedance of the objectives/guideline values results in unacceptable risk Steps 7 and 8 of the WQMF are triggered.

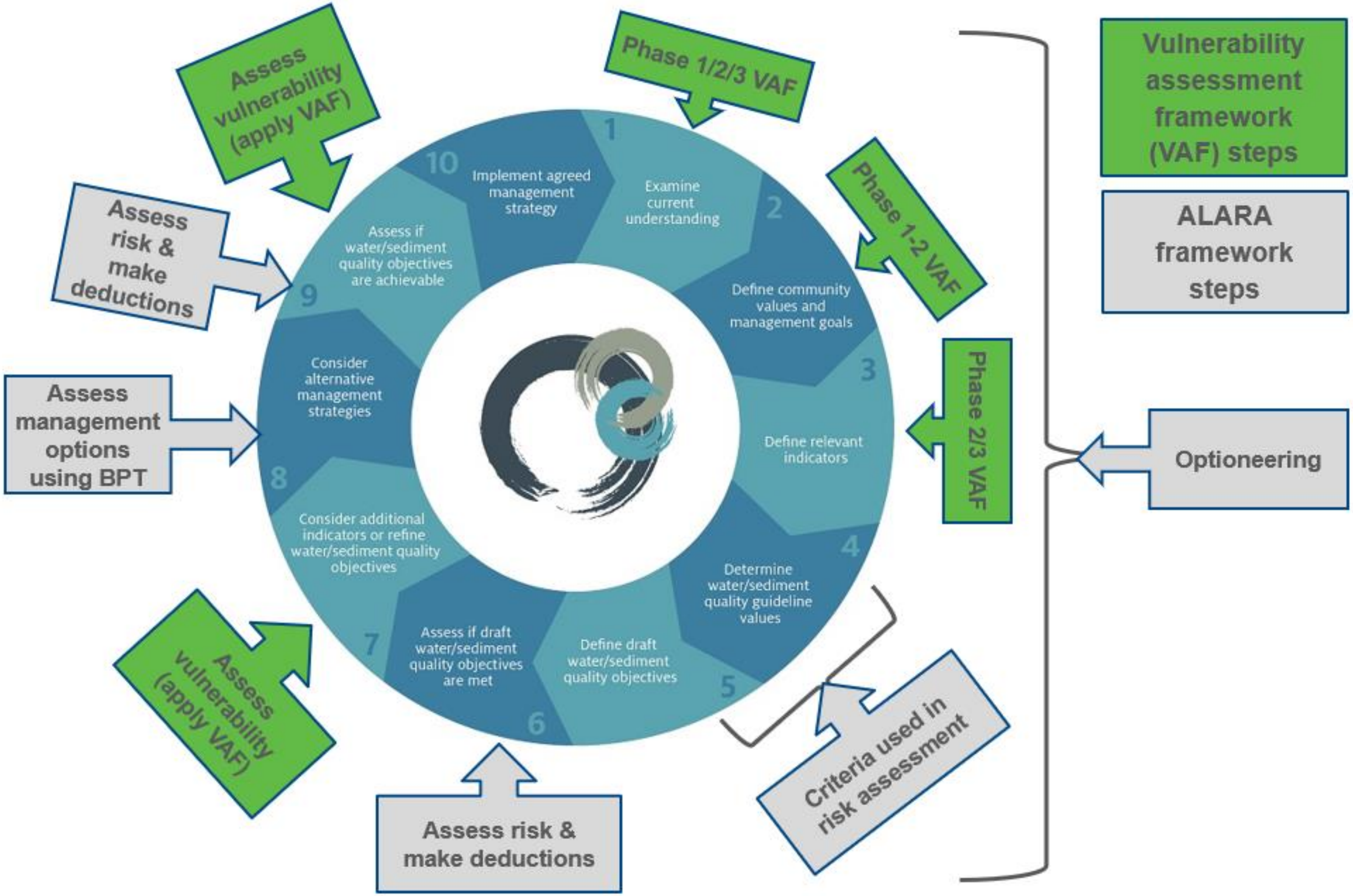

Figure 2 **Alignment of the WQMF (central wheel) with the ALARA and vulnerability assessment frameworks**

Step 7 of the WQMF involves a review of additional information and possible amendment of the criteria. The activities at this point differ for water bodies on and off the RPA. A review of conservatism in the solute transport models that provide the predicted water quality following closure is relevant to all sites being modelled and assessed. For water bodies on the RPA the VAF (section 2.2.2) is applied to provide an additional line of evidence to support discussions on whether impacts on the RPA are and ALARA.

Step 8 of the WQMF, relevant to both on and off the RPA, considers alternative management options. For this ERA uses the BPT and ALARA processes described in section 2.3. Step

It is important to note that Traditional Owners have reported concerns about trying to integrate cultural values with the ''scientific, legal and technical domains of a process that will take place within a framework controlled by those from the dominant non-Indigenous culture'' (Garde 2015). The application of this framework has been, and will continue to be, discussed with stakeholders, including the representatives of the Traditional Owners through working groups, consultative forums and site visits. This is particularly important for agreeing on management goals for waterbodies on the RPA and determining if impacts are ALARA.

2.2 Risk assessment and ecological vulnerability

2.2.1 Environmental risk assessment

A key environmental risk on site is the release of dissolved substances from mineralised and contaminated materials in mine areas (Bartolo et al. 2013). An understanding of potential impacts from these contaminants on environmental and cultural values is an important element of planning for closure. Studies have been conducted for over 40 years to understand the contaminants and nature of, and risks to, the health of the ecosystem and people.

An assessment was conducted by ERA and BMT Ltd (Iles & Rissik 2021) to identify the risks posed from the different contaminants and contaminant sources on the mine site or predicted to come from the site after closure. The assessment was conducted using the ERA risk assessment tools modified to make use of the detailed evidence available for the site. Quantitative predictions of future water quality (including predictions for 10,000 years) and evidence of existing contamination was compared to water and sediment quality objective and guideline values identified in Steps 4 and 5 of the WQMF. The risk assessment fits into Step 6 of the WQMF and is also an activity under the ALARA framework (section 2.3.2). At several sites risks were identified which triggered application of the VAF (section 2.2.2) and a review of solute transport model conservatism and management options. These activities are part of the WQMF (Steps 7 and 8) and the ALARA framework.

A separate paper in these proceedings (Iles & Rissik 2022) describes the risk assessment.

2.2.2 Ecological vulnerability

Ecological vulnerability assessment fills the knowledge gap that exists between laboratory and field effects experiments on a sub-set of species or assemblages, to understanding risks to higher levels of organisation and/or to other species and species groups (De Lange et al. 2010). Ecological vulnerability assessment considers not only the direct sensitivity of organisms to a stressor, but the potential for indirect flow-on effects through trophic and habitat relationships.

ERA commissioned BMT to develop a framework (the VAF; Figure *4*) to assist in understanding the potential impacts from contamination levels of magnesium greater than the 99% species protection guideline value. The initial phases of the project identified relevant water types, environmental values and indicators for waterways at, and adjacent to, the RPA which specifically reflect community values and meet statutory requirements outlined in the ERs (BMT WBM 2017). The later phases of the project developed the VAF to assess the vulnerability of the key species and functional groups identified as important ecological components underpinning the environmental values related to the ERs (BMT 2001).

The VAF assesses (i) exposure of ecological components based on water quality modelling and distribution of identified indicator species/communities, (ii) their direct and indirect sensitivity to contaminant exposure based on laboratory and field studies, and (iii) their capacity for recovery based on a review of the traits of ecological components. A separate paper in these proceedings (Richardson et al 2022) provides detail on developing and applying the VAF to Ranger waterbodies. The findings provide information of the vulnerability of the important ecosystem components for water quality predicted to occur under modelled closure scenarios. Knowledge gaps are identified and plans to address these are underway.

The understanding of ecosystem response to predicted water quality for given closure scenarios provides important information for deciding if impacts are acceptable and ALARA or if additional/alternative management strategies are needed.

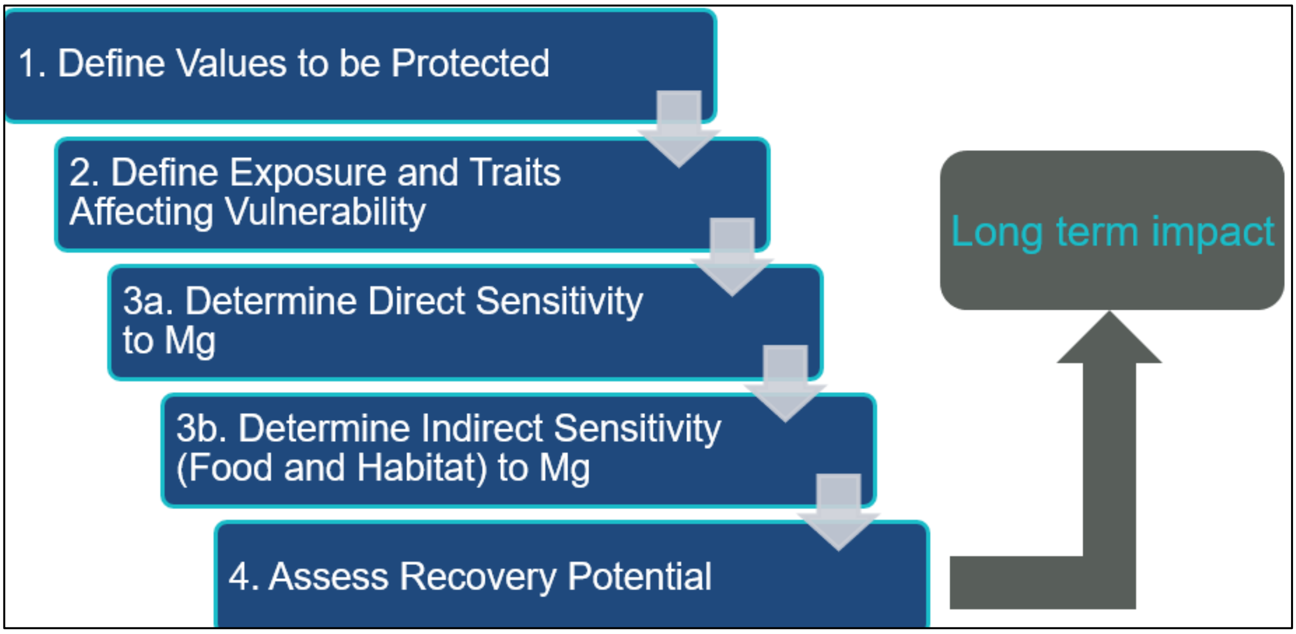

Figure 3 **The ecological vulnerability assessment framework (VAF) (source BMT 2021)**

2.3 ALARA & BPT

2.3.1 Best Practicable Technology

To comply with the ERs, the closure of Ranger must be implemented in accordance with BPT. SSB interprets BPT as the technology that is consistent with achieving the primary environmental requirements and ranks highest when considering: world best practice, cost effectiveness, proven effectiveness, Ranger's location, age of equipment and social factors (Supervising Scientist 2000). To ensure the BPT concept was effective for driving the closure strategy at Ranger, ERA expanded these categories to include cultural and heritage aspects and protection of the environment in the closure criteria themes of tailings, water, sediment, erosion and ecosystem establishment (Johnston & Iles 2013). The new criteria remained consistent with the original broad matters in the formal definition of BPT (ERA 2020). ERA reviews and updates the BPT criteria to keep them relevant to the phase of operations. This is done as part of the continuous improvement cycle and in consultation with stakeholders.

The BPT assessment process compares different management options and ranks them against each other based on scores for each of the BPT criteria. All scores are combined to a single value and the different options ranked (ERA 2020). The option with the best score is deemed to be BPT and taken through further assessments including further detailed risk assessment and BPT assessment of operational and design options for the chosen option.

Criteria can be weighted, and this has been suggested as a means of ensuring the highest level of protection for waterbodies and riparian zones and for allowing options to be compared on their technical ability to reduce impacts as well as comparison based on their cumulative score for all criteria. The risks associated with an option identified by such a weighted process would need to be assessed.

2.3.2 As Low as Reasonably Achievable

The ALARA procedure is a stepwise options assessment process followed to arrive at an option that represents the most acceptable result. ALARA is well established for radiation protection but is not directly transferable to assessments of non-radiadiological hazards such as chemical pollutants. A fundamental issue is the difference in approach between optimising radiation protection and control of chemical pollution. The former is recognised as using a top-down approach, while the latter is based on a bottom-up approach (Domotor et al. 1999, Tran et al. 2000).

According to Tran et al (2000) in radiation safety a top-down approach sets an upper limit and practices are put in place, using the ALARA procedure to consider cost and other factors, to reduce the risk further. The bottom-up approach works the opposite way. Numeric targets are based on an acceptable risk range. A target is set to limit exposure to the lower end of the acceptable risk range. If after considering the technical feasibility, costs, and other factors it is demonstrated the target is not achievable a decision may be made to accept a higher risk and set a target allowing exposure at the upper end of the acceptable risk range.

The ANZG (2018) WQMF for setting water quality criteria follows a bottom-up approach as described by Tran et al. (2000). The water quality objectives adopted by SSB as rehabilitation standards for water leaving the RPA are an example of numerical risk targets. If the targets cannot be achieved steps in the WQMF can be followed and alternative targets proposed. There is a need though to do this in the context of demonstrating relaxed targets are aligned with impacts that are ALARA.

Tran et al. (2000) recommends a flexible risk management framework and assessing multiple or cumulative risks as an approach to dealing with the differences between the top-down radiation safety ALARA approach, and the bottom-up numeric targets approach. Bryant et al. (2017), modified the radiation safety ALARA procedure to sit within a holistic hazard assessment framework for multiple hazards (Figure 4). ERA is adopting this framework of combined options-risk assessments in an iterative approach to identify a rehabilitation strategy with environmental impacts on the RPA from exposure to chemical pollutants that are ALARA.

The optioneering stage of the ALARA framework is where goals and criteria are established, and multi-criteria decision analysis of potential options is undertaken. ERA uses the WQMF to set goals and criteria and the BPT framework for decision analysis. This is where options that would achieve contamination that is as low as technically possible can be considered.

The risk assessment stage is where the environmental risk assessment and VAF occur along with other assessments in the ERA risk management process (e.g. assessments of health, safety and compliance with other closure requirements). Options and risk assessments are also steps in applying the ANZG (2018) WQMF.

If the impacts are not acceptable then steps in the ALARA framework (and the WQMF) can be revisited with discussions on cost, technical feasibility, and social expectations occurring to identify alternative management options.

Domotor et al. (1999) says ALARA is not a given value or numeric limit but is a process to assess a situation and ensure appropriate factors are considered. ERA propose that the water quality associated with the ALARA option (identified through applying the ALARA framework) be considered as numeric closure criteria (ERA 2020). Stakeholders agreed with this approach coupled with discussions on whether the proposed management option and resulting impacts are reasonable.

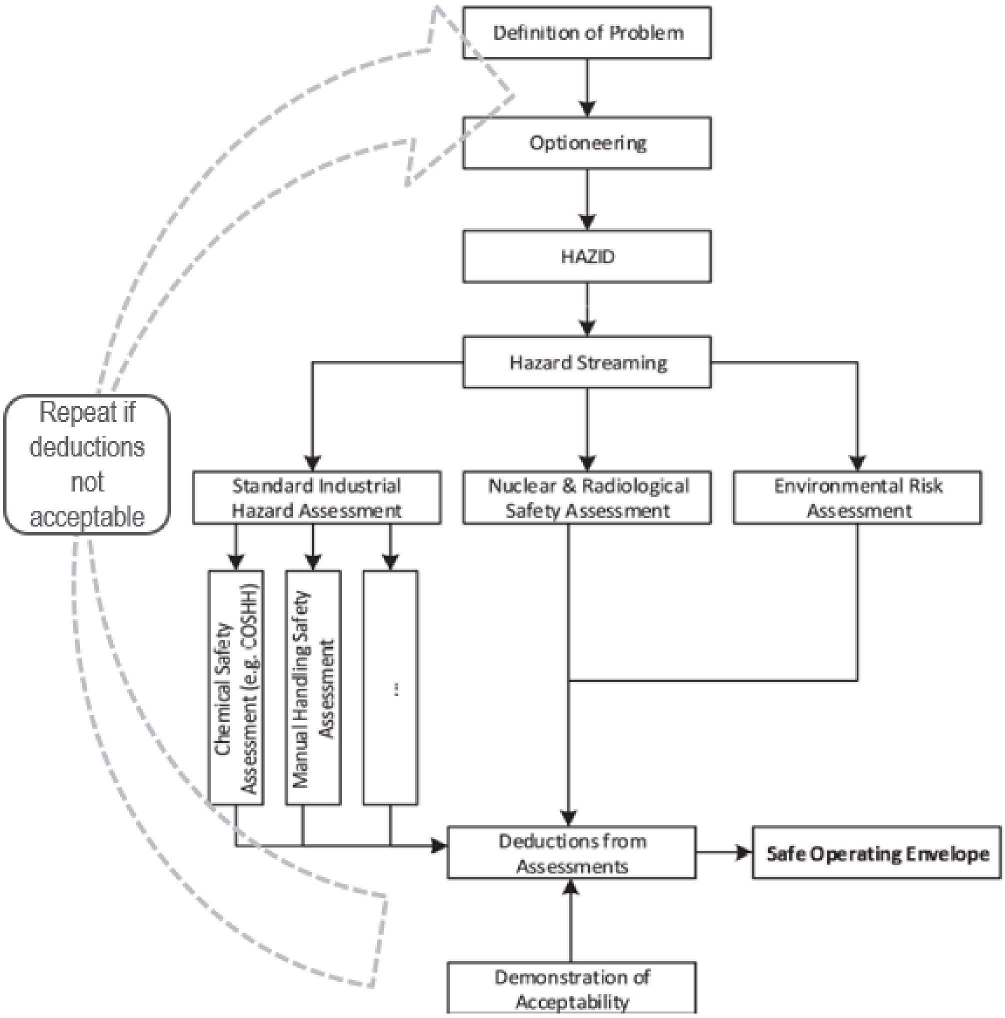

Figure 4 Framework for the integration of risks from multiple hazards into a holistic ALARA demonstration (modified from Bryant et al 2017)

3 Conclusion

ERA has applied multiple frameworks to inform derivation of water quality closure criteria for the Ranger mine to protect people, the ecosystem, and the World Heritage and Ramsar values of KNP and impacts that are ALARA on the RPA. The ANZG (2018) WQMF is central to this and is related to the other frameworks that are being used.

Deriving goals, indicators and guideline values that support the legislative ERs and Traditional Owner expectations occurs both within WQMF and the optioneering step in the ALARA framework. Assessing compliance with these is done by conducting assessments of source-pathways-receptor risks and ecological vulnerability. These are done under their own frameworks but sit within the WQMF and ALARA frameworks.

Using the approach demonstrated by Bryant et al (2017), ERA's BPT and risk management processes can be used, iteratively if required, to identify closure options that provide an ALARA outcome according to the process.

ERA has proposed that (i) by applying the ALARA framework in an iterative manner, management options that have been assessed as BPT and have acceptable levels of risk and impact (compared to management goals) can be identified, and (ii) the water quality associated with this option be used as closure criteria for water bodies on the RPA.

Stakeholders agreed with this approach coupled with discussions to determine if the proposed option is reasonable considering what is technically possible. Flexibility within the BPT decision making process can be used to assess options that provide as low as technically possible pollution control. Demonstrating the application of the ALARA framework and WQMF and sharing results from the BPT, risk assessment and VAF activities undertaken within these frameworks is vital to inform these discussions.

Acknowledgement

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