ERA Energy Resources of Australia Ltd

6 Best practicable technology

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Cover photograph: Ranger Mine (August 2020)

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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
ARRTC	Alligator Rivers Region Technical Committee
BC	Brine Concentrator
BPT	Best Practicable Technology
CCWG	Closure Criteria Working Group
CRF	Cemented Rock Fill
DEM	Digital Elevation Model
DITT	Department of Industry, Tourism and Trade
DPIR	Department of Primary Industry and Resources (now DITT)
EDR	Electro Dialysis Reversal
ER	Environmental Requirements
ERA	Energy Resources of Australia
HDS	High Density Sludge
ITWC	Integrated Tailings and Water Closure (Prefeasibility assessment)
MNES	Matters of National Environmental Significance
MTC	Minesite Technical Committee
NP	National Park
OHS	Occupational Health and Safety
RL	Relative Level
RO	Reverse Osmosis

Abbreviation/ Acronym	Description
RPA	Ranger Project Area
SSB	Supervising Scientific Branch
TSF	Tailings Storage Facility
VSEP	Vibratory Shear Enhanced Processing
WTP	Water Treatment Plant

6 BEST PRACTICABLE TECHNOLOGY

6.1 Introduction

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 Environmental Requirements (ERs) within Section 3 specify that:

> *12.1 All aspects of the Ranger Environmental Requirements must be implemented in accordance with BPT*
>
> *12.2 Where there is … agreement … that the primary environmental objectives can be best achieved by … (an) action which is contrary to the Environmental Requirements … and which has been determined in accordance with BPT, that proposed action should be adopted*
>
> *12.3 All environmental matters not covered by these Environmental Requirements must be dealt with by the application of BPT.*

The definition of BPT in the ERs establishes a framework for assessment of currently available technology at any point during the operational and rehabilitation phases of mine life, rather than the ERs specifying particular technologies which may become obsolete (Supervising Scientist 2000).

A method to allow assessment of BPT was proposed by the Supervising Scientist Branch (SSB) and published in their 2000/2001 Annual Report (Supervising Scientist Division 2001). This has been historically used by Energy Resources of Australia Ltd (ERA) to support major proposals for amendment to the Ranger Authorisation.

The current ER definition of BPT and an explanation of each BPT clause is presented in Table 6-1.

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

Environmental Requirement Clause	Explanation
Annex A - 12.4 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 factors below 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 must be 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.

Environmental Requirement Clause	Explanation
(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 should be 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 should be 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, on Aboriginal land surrounded by Kakadu National Park (NP), remote from high population density cities. Hence the level of protection required for the environment and community is very high and the technology chosen should be 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 should be reviewed periodically to determine whether or not recent advances have been made that would result in enhanced environmental protection. Technology installed at the Ranger Mine in accordance with BPT should be reasonably allowed to fulfil its serviceable life with due consideration given to the advances in technology and the amount of serviceable life expended.
(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 must be incorporated into BPT assessment. This includes where the introduction of new technology would 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.

Source: (Supervising Scientist Division 2001)

The determination of BPT for the closure of Ranger Mine was primarily undertaken during the 2011/12 Integrated Tailings, Water and Closure Prefeasibility Study (ITWC PFS) (Johnston and Iles 2013), included as Appendix 6.1.

Sections 6.2.9 and 6.2.10 present the outcomes of the ITWC study. The outcomes of the supplementary BPT assessment for additional tailings treatments conducted in September 2016 are provided in Section 6.2.11.

Several rehabilitation/closure activities were identified for standalone assessment via the Minesite Technical Committee (MTC). BPT assessments will accompany each application submitted to the MTC for assessment, as per the provisions outlined in the Ranger Authorisation. A summary of those submitted to date are provided in Section 6.3.

6.1.1 BPT assessment criteria

Early BPT assessments for the Ranger Mine ranked technology alternatives against the criteria presented in Section 6.1. For the ITWC PFS, ERA ensured that the issue of BPT was considered from the outset by all members of the study team.

Updates were presented to stakeholders at various stages throughout the study on progress of the assessment of BPT. Details of these meetings are included in the stakeholder engagement register presented as Appendix 4.1 and included nine presentations to the Alligator Rivers Region Technical Committee (ARRTC) between 2011 and 2016 and a presentation to the Closure Criteria Working Group (CCWG) in October 2016.

BPT has been a principal driver of the project and adoption of this procedure ensured that proposals emerging from the prefeasibility study would be demonstrably consistent with the requirements of BPT.

In considering the best procedure for ensuring the BPT concept became a driver for the project, as well as an assessment tool at its completion, ERA has developed a more detailed assessment matrix than had been applied in the past.

The 25 criteria that were used in the ITWC PFS and subsequent BPT assessments to rank technology alternatives for closure 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 values of Kakadu NP?
- Whilst 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 being considered 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 and how robust is it in response to variations in feed and consumables? Effective, highly robust options would rank highly.
- Does the standard of environmental protection achieved by the option meet the highest standards achieved in uranium mining elsewhere in the world?
- Does the capital cost of the option ensure its adoption would contribute significantly to the overall project value?
- How robust is the option with respect to variations in rainfall and requirements on the timing of mill closure?

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 ensure its continued viability?
- Is the process operationally reliable? That is, will it have high availability, or will it be sensitive to the failure of single plant items?
- Would the option be difficult to maintain?
- Would the operating costs associated with the option have a large impact on overall project value?

Rehabilitation and closure:

- Would adoption of the option ensure the establishment of a revegetated site using local native species with a low maintenance regime?
- Would the option ensure the establishment of 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?
- Would the option enable the establishment of stable radiological conditions on the rehabilitated site that will ensure that health risks to members of the public meet Australian standards and are as low as reasonably achievable?
- Would adoption of the option ensure agreed water quality criteria are met in creeks draining the mine site and appropriate ecosystem rehabilitation standards are achieved for water bodies on the rehabilitated landform?

- Would adoption of the option ensure all tailings produced at the Ranger site are physically isolated from the environment for a period of 10,000 years and any contaminants arising from the tailings will not result in any detrimental environmental impact for at least 10,000 years?
- Would adoption of the option extend closure beyond Traditional Owner expectations and, in particular, beyond the requirements specified in the section 41 Authority?

Constructability:

- Would adoption of the option introduce significant health and safety risks to the workforce during the project construction phase?
- Will the option give rise to the need for significant land disturbance during construction, significant off-site environmental impact or require construction work near sites of cultural significance?
- Would adoption of the option lead to high construction complexity through difficult scheduling, complex logistics or significant manpower requirements?

The new criteria remain consistent with the original six broad matters in the formal definition of BPT.

Implicit within the Traditional Owner Culture and Heritage, Protection of People and the Environment and Rehabilitation and Closure criteria is an assessment of the option against

- the Ranger Mine closure criteria themes (Section 8)
- the various Matters of National Environmental Significance (MNES) protected by the controlling provisions of Part 3 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) which include the World Heritage living cultural and environmental values and the Ramsar wetland values

6.1.2 BPT ranking, weighting and scoring

The BPT assessments incorporate a 5-level technology ranking system where a ranking of three indicates that the option meets industry standards (Table 6-2).

The final BPT score for each technology option is calculated using the rank of the option against each of the criteria.2 The BPT score essentially summarises performance of the option against current international performance standards. The score for an option which achieves the highest rating for all criteria would be 100 whilst an option that meets standards for all

2 BPT score = $100\Sigma_{i=1,N}$ $(s_i – 3)/(N.2)$ where si is the score for criterion i and N is the total number of criteria for which a score was recorded. Only criteria for which a score was recorded (rather than a UTE or NA result) were included in the summation process.

criteria would score 0 and an option that achieves the lowest rating for all criteria would score -100.

In addition, two types of show-stopper results were possible. A hard show-stopper was 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 initial assessment demonstrated that adoption of an option could result in intrusion on a sacred site. A soft show-stopper would be 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 issues 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.

Table 6-2: BPT technology and ranking system

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.
UTE	Unable-to-evaluate (UTE) - insufficient information available to allocate a rank to a criterion.
NA	Not applicable (NA) - the criterion was not applicable to the option being considered.

6.2 Completed closure-related BPT assessments

6.2.1 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 continues 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 is 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 has 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 does not require a BPT assessment. However, the reduction in crest height to a level that enables the completion of dredging presents 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 therefore 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 6-3).

Most of these 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 negate 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 justify the selection of option A2 over option A3.

The BPT assessment matrix for TSF North Notch Stage 3 is included in Appendix 6.1.

Table 6-3 BPT assessment options and overall ranks for North Notch Stage 3

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.	0.0
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.	0.0
A3	Construct North Notch 3 to RL 36.3 m RL. Infill the notch to Stage 2 level following completion of TSF cleaning operation.	0.0
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-stopped
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

6.2.2 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 Tailings Storage Facility (TSF) and Pit 3. The assessment was aimed at assessing the environmental impact of leaving the contaminated material in situ in versus disposal in Pit 3. The reason for this tightly defined scope was to determine if the planning and application for the closure of Pit 3 is required to consider this subfloor material. The deconstruction of the TSF does not occur until 2024 and, as such, this application was submitted prior to the Pit 3 application and the actual Pit 3 capping works. In order to finalise the Pit 3 capping design, ERA needed to complete an assessment to determine if Pit 3 was a viable option for the final storage of TSF subfloor material and, subsequently, gain stakeholder acceptance of this assessment. Based on the outcomes of a BPT assessment, an application was submitted to the Director of Mining Operations, DPIR (now DITT) for approval in March 2020. The application updated in June 2020 following stakeholder feedback and the DPIR (now 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 6-4). Option 1 was developed as a "worst-case" scenario for leaving the material *in situ*. Option 2 was omitted from further assessment, at this stage, 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 6-4 BPT assessment options and overall ranks for TSF Contaminated Material Management

Option	Option description	Overall Rank
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
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	Initial show-stopper

Option	Option description	Overall Rank
	secondary cap with remainder to other onsite storage cell. TSF used for process water storage.	
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 comparatively evaluate 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 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.

Option 3a.1 (Pit 3, 2 m, secondary cap) was the highest rank of the Pit 3 transfer scenarios, second highest rank overall and resulted in the second lowest number of soft show-stoppers overall (4 out of 10). This option scored -17.6 and indicated it could meet or exceed current standards for Revegetation, Cultural Heritage, Environmental Protection, and Erosion aspects. However, soft show-stoppers were identified for Living Culture, Ecosystems & Natural World Heritage, Community Health and Safety, and Radiation (Closure). This option scored equal lowest for Water (“1”) as the solute egress modelling outputs indicated a significant magnesium loading to the environment. All other Pit 3 options received overall ranks of less than -20.

The options 3a.2, 3a.4, 3b.1 and 3b.2 were hard show-stopped based on initial assessment indicating that these would not be practical approaches.

The BPT assessment matrix for TSF subfloor material management is included in Appendix 6.1.

6.2.3 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 overall rankings (31 – 44.4) and differed marginally in the weighting of individual criteria namely robustness, CAPEX, schedule and construction complexity (Table 6-5).

Table 6-5 BPT Overall ranking for HDS recommissioning and release

Option	Option description	Overall rank
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

Option	Option description	Overall rank
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.

The BPT assessment matrix for HDS plant recommissioning is included in Appendix 6.1.

6.2.4 Subaqueous tailings deposition into Pit 3

Report: *Application Pit 3 Tailings Deposition, 2019*

In preparation for cessation of mining and processing activities at Ranger Mine an assessment of 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
- accelerate backfilling with consolidated tailings (ERA, Alan Irving & Associates 2019).

Following detailed assessment of various subaqueous deposition configurations and multi-spigotted, subaerial deposition options for Pit 3, a BPT assessment was undertaken in January 2019 (GHD 2019) to assess the range of potentially viable deposition options. To conduct this assessment, tailings under consideration were separated into either mill tailings or dredge tailings and scored against the six major criteria (Section 6.1.1).This resulted in an overall ranking calculated for each option (Table 6-6).

Table 6-6 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 the majority 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. This would negatively impact on the closure schedule and result in ERA unlikely to meet the closure date of January 2026.

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 depostion from multiple spigots on the east wall) and D2 (dredge 1 and 2 subaqueous) was selected as this combination also facilitates achievement of the target completion date of 2026.

The BPT assessment matrix for tailings deposition options for Ranger Pit 3 is included in Appendix 6.1.

6.2.5 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 was 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 its 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)
- erosion and sediment control features have been refined based on conceptual designs developed in 2017

The DEM was also provided to the MTC for assessment and SSB feedback is included in the change application report (ERA 2019a). The Pit 1 Progressive Rehabilitation Monitoring Framework were developed to facilitate successful rehabilitation of Pit 1 and inform ongoing rehabilitation across the RPA. These additional works support ERAs continued backfilling of Pit 1 in preparation for initial tree planting of the Pit 1 landform surface scheduled to commence in early 2021.

An application was submitted to the Director of Mining Operations, DPIR (now DITT) in March 2019 in accordance with the requirements of the Ranger Authorisation issued under the *Mining Management Act* (NT) and 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
- 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 (Section 6.2.5)

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 considered to be optimal. In particular, bulk backfilling of Pit 1 is nearly complete are there are no major competing alternatives for the bulk backfill methodology. The final landform design, originally described in 2006, continues to be revised based on changing stockpile material grades, volumes and locations. When refining the landform design, revisions are made with consideration of several goals:

- adherence to landform design criteria (general physical attributes)
- minimise disturbance outside of the existing disturbed area footprint
- reduction of the visual impact of the landform by eliminating the use of batter slopes
- general reduction in slope gradients, resulting in improved view-shed from Magela Creek
- minimise rehandling of material on closure
- consideration of material grades, volumes and their locality in the landscape at cessation of mining

Alongside these goals, as revision of the final landform construction occurs, requirements at the forefront of consideration are the need 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 subsequent modelling done to address landform design and backfill planning are consistent with the general practice of BPT assessment.

6.2.6 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 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 has 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 used to assess 27 options with potential to process the WTP brines. 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 take to an order of magnitude assessment level. A second, tier II, 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 tier II BPT assessment showed the Brine Squeezer (Figure 9-1) 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 have been used to inform a tier II assessment and revise the relevant criteria of the 2013 BPT assessment, using the same BPT options screening criteria and ranking system. 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 6-7) However, given the sensitivity of the ranking to minor variation in rankings for each category, the spread in scores across the three options was not considered material.

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 proposed plant, to be installed in the existing sand blast yard, comprises three trains, providing for 99 percent availability of two trains (1 standby/cleaning).

Table 6-7 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

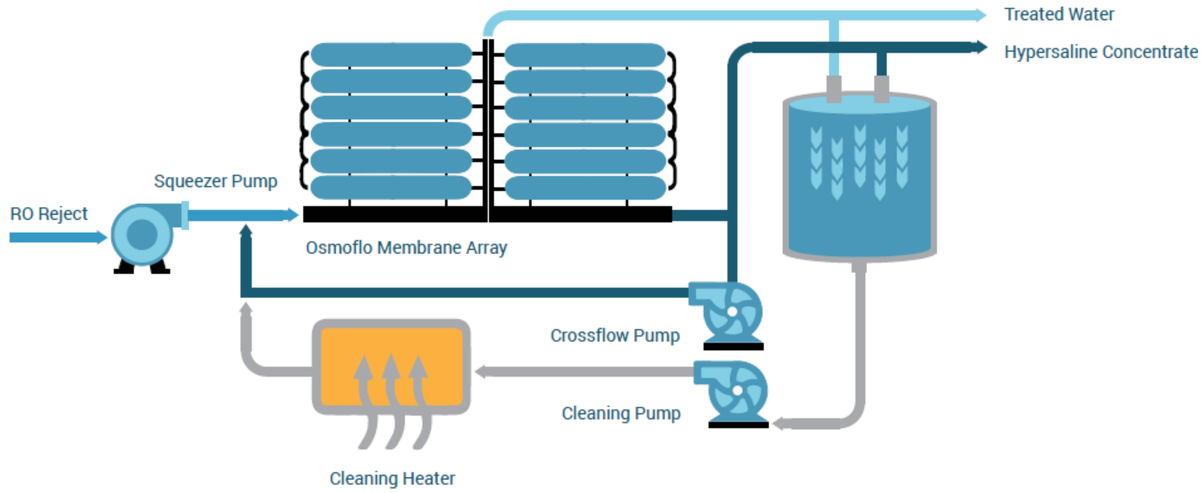

Figure 6-1: Brine Squeezer process flow diagram (source: http://www.osmoflo.com/)

The Osmoflo Brine Squeezer has the capacity to reduce the WTP brine contribution to process water by 200 to 1,000 ML/year. Based on this, the installation and operation of the Brine Squeezer meets the 2017-18 Ranger Water Management Plan objectives three and four:

- minimise unnecessary additions to the pond water and process water inventories
- optimise pond and process water treatment, and disposal mechanisms

The outcome of the BPT assessments showed the Brine Squeezer to be the highest ranking option, leading to its selection for acquisition, construction and commissioning of a Brine Squeezer to treat WTP brines. Commissioning of the Brine Squeezer commenced in June 2019, with the plant expected to be fully available for the 2019/2020 wet season.

The BPT assessment matrix for brine minimisation is included in Appendix 6.1.

6.2.7 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 blackjack 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 Environmental Requirements. 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 6-8).

Table 6-8 Black jack disposal options and best practicable technology assessment summary

Option	**Option description**	**Overall rank**
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

According the results of this BPT assessment, Tellus' National Geological Repository (Option A1) received the highest overall rank, with 50 points. The second highest was Scholer's Waste Oil Incinerator, total ranking of 23.8 points. To further support Scholer's Waste Oil Incinerator (Option A2), ERA will need to complete an air quality study and confirm that the incinerator will include environmental air pollutant control mechanisms – e.g. baghouse, scrubber, etc.

Although Tellus ranked higher, at the time of the assessment it was yet to receive final approval and licencing to accept low-level radioactive waste. In April 2019, local government approval was secured to develop the facility following approval by the Commonwealth government in January 2019. Tellus has completed Stage 1: Enabling works and Stage 2A: Installation of a permanent village. The project is on track for Stage 2B: Balance of works by August 2020.

6.2.8 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 6-2) continued until December 2014 whilst simultaneously submissions were made for the construction of the R3D underground mine. 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.

A BPT assessment of the closure involved a 5-level technology ranking system, where a ranking of three meets industry standards. A final BPT score for each technology option was calculated through summing an assessment of the technology against applicable BPT criteria.

The primary objective of the assessment was to determine which combination of options constituted BPT for 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
- 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 takes into consideration ground conditions and potential heavy mobile equipment limitations (i.e. gradient, manoeuvrability, etc). The assessed option and BPT outcomes are presented in Table 6-9.

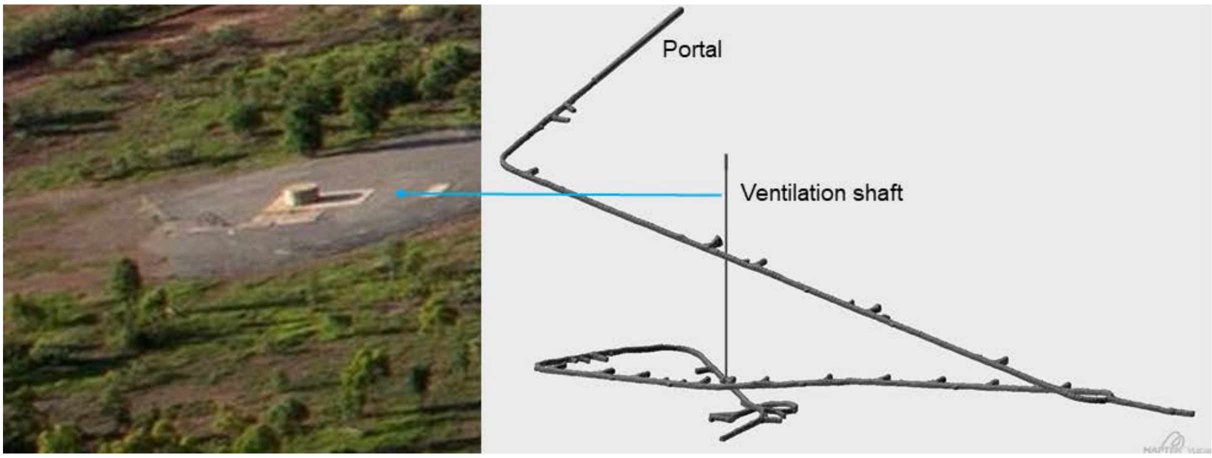

Figure 6-2: Aerial view of the ventilation shaft and underground infrastructure

6.2.8.1 Decline closure

For the decline, options A1 and A2 rated poorly in comparison to the other options and were soft show-stopped on the basis of 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, fitness for purpose, whilst option A7 (waste rock placed in the weathered zone) was allocated the highest assessment score of 41.7.

6.2.8.2 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 in 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 therefore, ranked as the preferred option for portal closure.

Table 6-9: 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

Option	Option Description	Overall Rank
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

6.2.8.3 Ventilation shaft closure

Five of the ventilation shaft options were hard show-stopped on the basis of 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. However, for its greater ability to mitigate potential long-term movement of groundwater to the surface via the ventilation shaft, 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.

6.2.8.4 Outcome

On the basis of the BPT assessment, preliminary tier 2 risk assessment and supporting technical studies, ERA propose a staged decommissioning and closure of the R3D exploration decline described in the '*Ranger 3 Deeps exploration decline decommissioning plan*' (Murphy 2018). The closure activities include the care and maintenance activities before final closure. Final closure includes backfilling the ventilation shaft, allowing the decline to flood to below the weathered zone, backfilling the decline above the weathered zone and dismantling and cutting the multi-plate steel tunnel down to ground level and covering with waste rock to blend with the final landform.

The BPT assessment matrix for R3D is included in Appendix 6.1.

6.2.9 Integrated tailings, water and closure prefeasibility study one technical options assessment

Report: *Integrated, Tailings, Water & Closure Prefeasibility Study: 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.

To assess the available technical options, separate BPT workshops were conducted to assess the following project components:

- tailings reclamation, transfer, treatment and deposition within Pit 3
- process water salt management and disposal within Pit 3, and
- final landform construction, revegetation and ecosystem reconstruction.

6.2.9.1 Tailings management

Options were considered for the reclamation, treatment and deposition of tailings for mine closure, which are described below, along with the key conclusions as a result of rating each option.

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 6-10).

Table 6-10: 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 assessments. 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 is 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 include high costs to construct, install and operate, and the maintenance requirements would be high. 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 as an option to potentially reduce dispersion of solutes in groundwater if required[3], 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 both would be sensitive to rainfall (a dry pit would be required).

Conclusions from rating options for tailings

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

- dredging is the preferred tailings reclamation method

[3] 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.

- cementation is not currently considered viable as a treatment method
- 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.

6.2.9.2 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 and were hard show-stopped prior to the workshop. A total of seven options were assessed in detail (Table 6-11).

Table 6-11: 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 OHS 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 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 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 on the brine injection option.

6.2.9.3 Final landform construction, revegetation and ecosystem rehabilitation

The assessment process adopted in the BPT workshop on landform construction, revegetation and ecosystem reconstruction was different to that adopted for tailings management and salt treatment and disposal. The landform reconstruction and revegetation program has gone through significant options analysis and refinement over several years and there are no longer major competing alternatives for their implementation.

Rather than assessing options and completing the ranking; each of the current plans for landform construction, revegetation and ecosystem reconstruction were reviewed against each criteria to identify possible options for improvement and to record any uncertainties.

Focus was given to closure schedule to determine the nature of any risks to completion of rehabilitation by 2026 as required under the section 41 Authority.

The BPT assessment matrix for tailings treatment is included in Appendix 6.1.

6.2.10 Prefeasibility study two: closure strategy and plan

After a thorough options review and the application of a detailed BPT assessment, available technical options were narrowed down to core technical options which relate to tailings management (dredged tailings with thickened tailings transferred to Pit 3 vs dredged tailings with thickened and filtered tailings transferred to Pit 3) and salt management (brine injection vs crystallisation). In all cases the option for transfer of tailings from the TSF to Pit 3 is by dredging, thickening then pumping.

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
- 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 6-12.

Table 6-12: 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

Strategy	Brine strategy	Tailings strategy	Milling end
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

6.2.10.1 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 which 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 6-3.

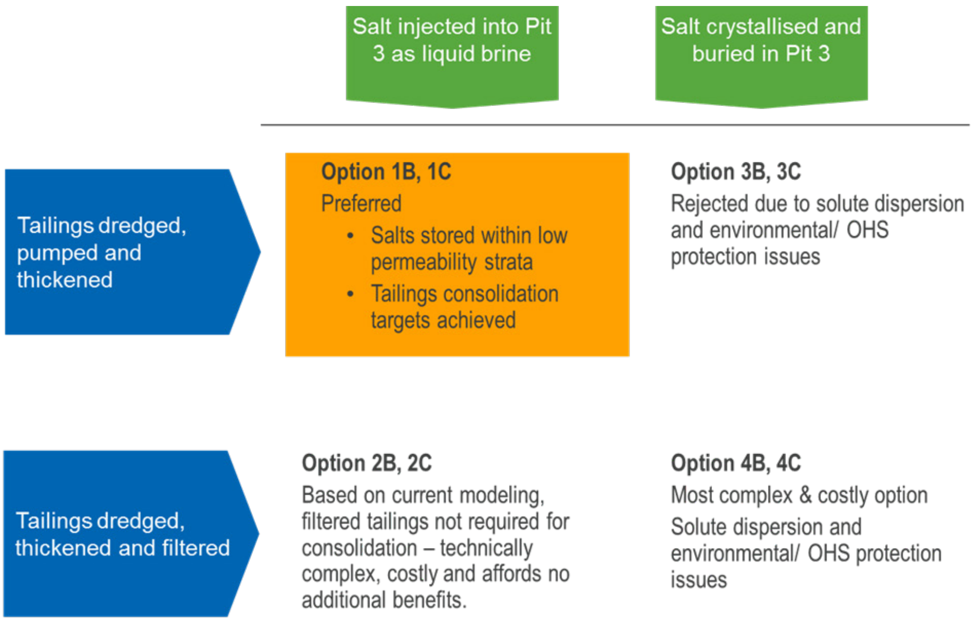

Figure 6-3: Outcomes of the stage 1 assessment

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.

6.2.10.2 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 if an extension beyond the 2026 closure date could be negotiated. Table 6-13 lists the options assessed in Stage 2.

Table 6-13: 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 on the basis of 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
- schedule: both extended options scored lower than the primary options under the schedule criterion

6.2.11 Supplementary integrated tailings, water and closure prefeasibility study BPT assessment

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.

The initial PFS 1 BPT assessment for tailings treatment included thickening as part of all options assessed. At the time of the ITWC PFS thickening was considered to be the base case for two reasons:

- to remove process water from the tailings prior to pumping over to Pit 3, thereby reducing the costs of pumping this water back to the TSF
- to assist in achieving final consolidation targets in Pit 3, to allow for backfill and completion of rehabilitation by 2026 as required under the section 41 Authority

Further test work, modelling and analysis undertaken since 2012 and the effective consolidation outcomes currently being achieved in Pit 1 has indicated thickening may not be required. To determine if there were options without thickening that could be BPT; a supplementary workshop was conducted on 8 September 2016.

The primary additional treatments considered in the assessment were scenarios associated with unthickened tailings deposition into Pit 3, including:

- unthickened (A2)
- unthickened with prefabricated vertical drains (wicks) (A3)
- unthickened tailings with extended water treatment (A4)
- unthickened tailings, with inline agglomeration and wicks (A5)
- unthickened tailings with neutralisation and wicks (A6)

Tailings treatments brought forward from the previous ITWC BPT assessments include:

- thickened tailings (A1)

- thickened and filtered tailings (A7)
- thickened, filtered and cemented tailings (A8)

A summary description of each option is provided later in this section.

Several key assumptions were identified during the assessment, which were taken into consideration when ranking individual strategies, including:

- processing to January 2021
- any additional process water treatment required would be in the form of an additional Brine Concentrator or expansion of the existing infrastructure
- use of lime as the preferred neutralisation option

6.2.11.1 Thickened tailings (A1)

The ITWC treatment options analysis assumed all tailings would be thickened as a base case. Under this option, tailings are to be reclaimed from the TSF by dredging and dewatered in a thickener prior to pumping the thickened tailings to the mined-out Pit 3. A schematic of the thickening option is presented as Figure 6-4.

The rationale was to reduce the volume of tailings deposited and thus the rate of rise, reducing time taken for consolidation and reduce the pumping costs associated with process water return from Pit 3. The plan was to implement thickening 12 months after the commencement of dredging.

The Ranger Mine mill thickens the tailings stream to approximately 50 weight percent solids prior to deposition in Pit 3, whilst the proposed TSF reclamation dredge will progressively reclaim the subaqueous tailings producing a 28 weight percent solids stream. Thickening prior to transfer to Pit 3 will increase the solids content to approximately 60 weight percent.

Consolidation modelling has shown the thickened tailings will achieve consolidation targets.

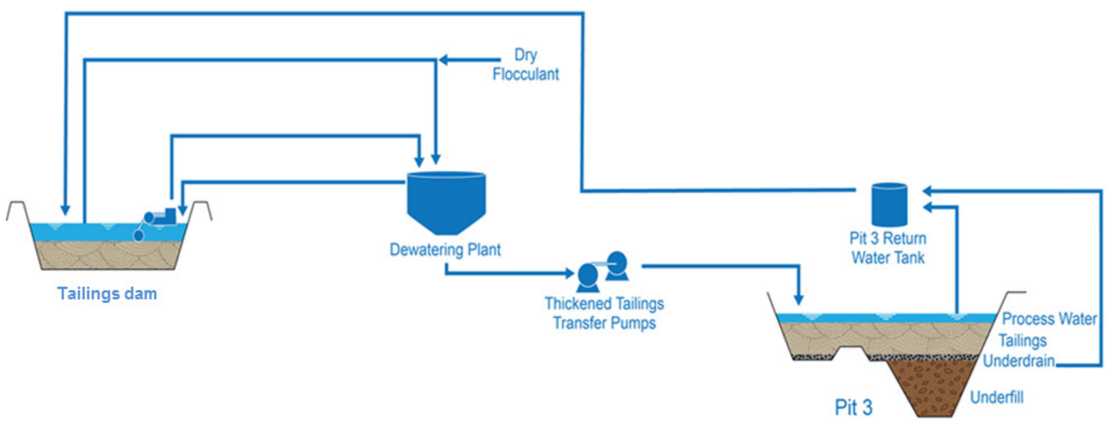

Figure 6-4: Thickened tailings flow sheet

6.2.11.2 Unthickened tailings (A2)

The unthickened tailings strategy involves the direct transfer of dredged tailings from the TSF to Pit 3, where it is allowed to naturally consolidate over time.

Dredged tailings have a solids density of approximately 28 weight percent. Following deposition in Pit 3, the tailings undergo sedimentation and release water and achieve an initial settled density. Sedimentation testing has shown that unthickened mill tailings discharged at 28 percent solids rapidly settle to about 55 percent solids whilst thickened mill tailings discharged at 50 percent solids settle to 56 percent solids; indicating that unthickened tailings may be a viable option.

Consolidation modelling was conducted to determine if any unthickened options would be able to achieve the consolidation targets by the schedule date of January 2026. Modelling demonstrated that consolidation could not be achieved without prefabricated vertical drains (wicks) to assist with the consolidation.

Based on this result, the option of unthickened tailings without further treatment was hard show-stopped.

6.2.11.3 Unthickened tailings with wicks (A3)

Consolidation modelling demonstrated the unthickened tailings option with the installation of wicks can achieve the required amount of consolidation by 2026.

Pit 1 has provided a working demonstration of the effectiveness of tailings dewatering and consolidation via the installation of prefabricated vertical wick drains. In 2012, 7,554 wicks were installed into the pit to assist with dewatering, ahead of capping and rehabilitation. The wicks were installed within the top 40 m of the tailings mass to dewater the upper level of the tailings and promote tailings consolidation, thus establishing a stable surface upon which to commence bulk backfill activities. A pre-load waste rock layer is placed over the tailings mass, designed to activate the vertical wicks by compressing the tailings and forcing the water in the pit to travel to the surface via the wicks and natural drainage patterns to decant towers located at the lowest points in the pit. Pumps, located in the decant towers, transfer the process water back to the process water system for treatment. Current consolidation modelling predicts that over 99 percent of the pore water in Pit 1 will be expressed within the first six years of consolidation. The installation of wicks in Pit 1 has proven to be an effective alternative technology to thickening and/or thickening with additional treatments.

6.2.11.4 Unthickened tailings with extended water treatment (A4)

This strategy is a variation on strategy A2 but includes extended water treatment past 2026, by way of construction and commissioning of an additional BC or expansion of the existing plant. Under this option, the landform over Pit 3 is surcharged and the tailings are able to complete consolidation. Process water expressed during consolidation would be captured and treated. This option is similar to the 5B and 5C in the ITWC PFS2 stage 2 BPT assessment.

The need for a second BC or expansion of the existing BC was based on the expected operational life span of the existing BC, not the volume requiring treatment.

6.2.11.5 Unthickened tailings, with inline agglomeration and wicks (A5)

Inline agglomeration involves the dosing of tailings with a flocculent, (i.e. a synthetic water-soluble polymer or aqueous liquid with dispersed particulate solids) that potentially reduces the dry density of tailings in the pit after consolidation (Figure 6-5).

A feasibility study was conducted in 2014 to quantify the costs and risks associated with inline agglomeration. The option was proposed as an alternative to the construction and operation of a high compression thickener. The feasibility study in 2014 followed laboratory scale testing (i.e. a scoping study) undertaken in May 2013, which demonstrated the viability of depositing flocculated tailings just above the floor of Pit 3 from a launder or pipe laid along the pit's haulage ramp. The study estimated that inline agglomeration could potentially reduce the tailings transfer costs, process infrastructure, flow sheet complexity and the risks associated with thickening the tailings from the TSF and managing foreign objects. However, if this option were to be adopted, the consolidation target would not be achieved without the installation of wicks.

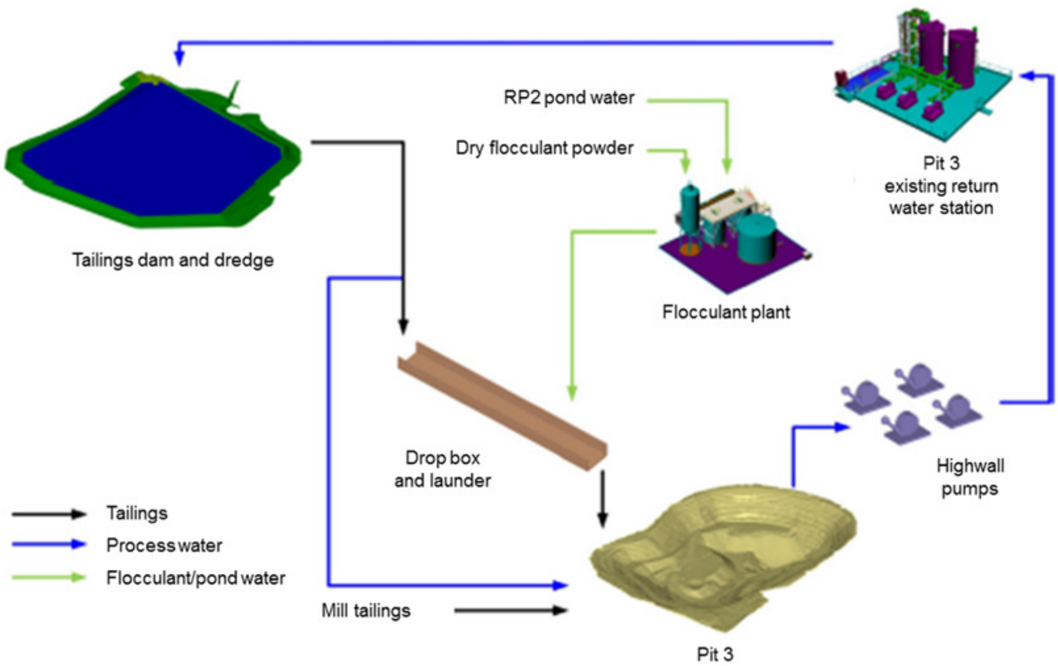

Figure 6-5: Inline agglomeration flow sheet

6.2.11.6 Unthickened tailings with neutralisation and wicks (A6)

Neutralised tailings are an alternative to cementation of tailings (Figure 6-6) and were thought to potentially lock up contaminants in the tailings, preventing detrimental environmental impact for 10,000 years. This treatment involves adding a reagent to the tailings stream to bind (reduce mobility) or precipitate solutes and/or radionuclide. Two examples of this method are:

- addition of lime, similar to the existing Ranger processing plant but to a higher pH target, and
- addition of spent liquor from the Gove Alumina Refinery – e.g. hydrotalcite [$(Mg_6Al_2(CO_3)(OH)_{16.4}(H_2O))$] precipitates.

Test work and analysis of this option determined a number of advantages and disadvantages (Table 6-14).

Table 6-14: Tailings neutralisation advantages and disadvantages

Advantages	Disadvantages
• avoids pipeline solidification issues associated with cementation • simpler process compared to cementation • avoids capital in cement facility, mixing and tremie/pump • lime neutralisation is proven technology at Ranger	• methods (i.e. hydrotalcite) not proven at Ranger • medium – high opex costs • 10,000 year stability not known • impact of expressed water solute loading and composition on water treatment not known • tailings would be more permeable than cemented tailings • impact on consolidation not known

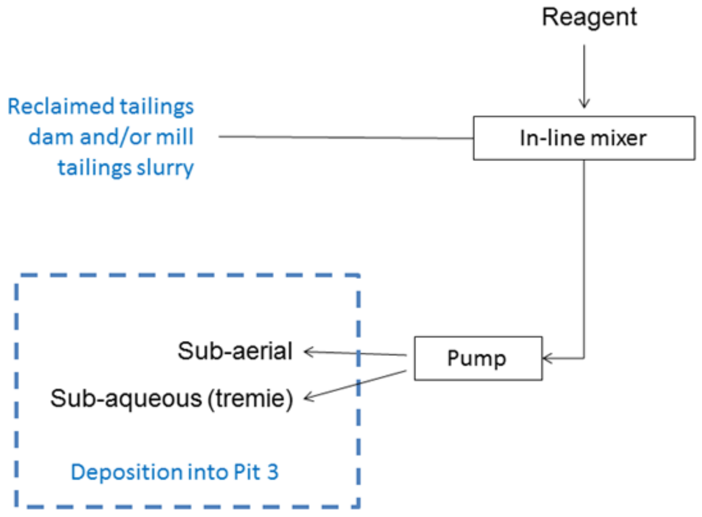

Figure 6-6: Tailings neutralisation flow sheet

6.2.11.7 Thickened and filtered tailings (A7)

Thickening followed by filtration was an option considered as part of the original BPT and was therefore included as part of this supplementary assessment.

The primary purpose would be to ensure prompt consolidation of tailings in Pit 3 and thus effectively eliminate tailings settlement after deposition. The proposed filter plant would process both the reclaimed thickened tailings from the TSF and the mill tailings using pressure filters. The filter cake would then be transferred via a conveyor system to a truck load out bin, hauled to Pit 3 and spread by dozers (Figure 6-7). Tailings filtration studies established that:

- pressure filtration was required to dewater mill tailings
- vacuum filtration was inappropriate technology for dewatering the whole tailings stream and was only suitable for dewatering the coarse size fractions.

The major advantages of filtered tailings over thickened tailings are:

- when placed and compacted the filtered tailings will reach a high overall density and a relatively low permeability. Thus, filtered tailings will express a negligible quantity of process water after placement, reducing post-closure water treatment
- filtered tailings will produce negligible settlement allowing earlier access for backfilling, thus accelerating the overall closure schedule.

However, compared with thickened tailings the main disadvantage of filtering is that Pit 3 must be dry before the tailings can be placed. This requires the construction of another process water dam. Other disadvantages include higher capital and operating costs, and increased health, safety and environment risks during operations.

6.2.11.8 Thickened, filtered and cemented tailings (A8)

Cementation of tailings was an option considered as part of the original BPT and therefore included as part of this supplementary assessment. Due to the high-water content of tailings, the solids concentration would need to be raised by both thickening and filtration in an appropriate plant before cementation occurred. Without this pre-treatment, cement consumption and the associated costs would be extraordinarily high and drying times would be long.

Tailings would be split with one fraction passing through a thickener and the other through a filtration plant and a hopper prior to combining both outputs in a mixer with a tailored mixture of cement and water. The mixer output would be held in a tank for conditioning prior to being pumped to Pit 3 (Figure 6-8).

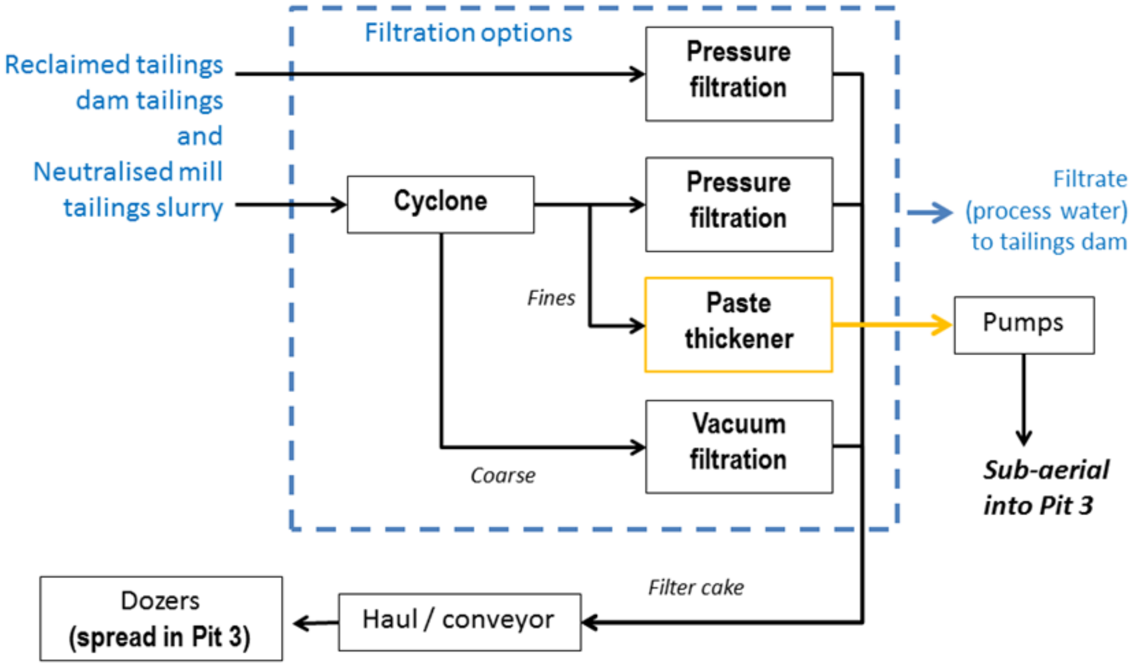

Figure 6-7: Tailings filtration flow sheet

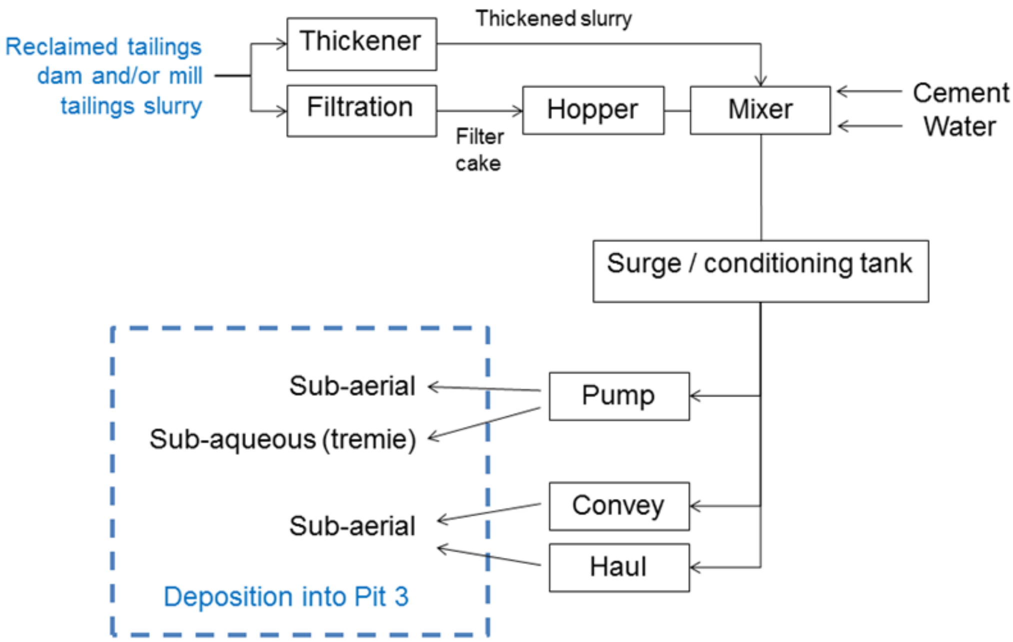

Figure 6-8: Thickened, filtered and cemented tailings flow sheet

6.2.11.9 BPT analysis of tailings treatment options

The eight options outlined in Section 6.3.11.1 to 6.3.11.8 were assessed using the same assessment criteria, scoring and weighting, as used in the ITWC PFS assessment; the results are presented in Table 6-15. Of the eight options assessed, one hard show-stopper and four soft show-stoppers were identified by workshop participants.

Table 6-15: 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

The full BPT assessment matrix resulting from the September 2016 workshop is shown in Appendix 6.1

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) has 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 Portland 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.

6.2.11.10 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. Further modelling indicates that tailings consolidation in Pit 3 can be achieved within the 2026 timeframe using this option.

The final closure strategy, and its implementation, is discussed in detail in Section 9.

6.3 ALARA and BPT

Several ERs require impacts to be as low as reasonably achievable (ALARA). ER 1.2(e) requires that environmental impacts within the RPA are as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation. In addition to requiring impacts on the RPA that are ALARA, the term ALARA also applies to:

- exposure of Aboriginals and other members of the regional community to radiation and chemical pollutants to (ER 1.2c),
- radiation health risks to members of the public (ER 2.2b)
- radiation protection of workers and the public (ER 5)
- impacts on the RPA from hazardous materials and waste (ER 6)
- management of excavated material (ER 7)

Traditional Owners have expressed an expectation that rather than achieving ALARA, rehabilitation in the riparian zones uses is as high as is technically possible and the level of contamination is as low as technically possible.

The ALARA concept is well defined and practiced in the world of radiation protection. The terms “ALARA” and “optimisation of protection” are now interchangeable in International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) documents (IAEA 2010).

The objective of optimisation is to achieve an appropriate balance between the efficient use of protection resources and the risks. The ALARA procedure is a stepwise options assessment process followed to arrive at an option that represents the most acceptable result. The ALARA procedure is well established for radiation protection but not directly transferable to non-radiation assessments.

Several countries have extended the concept of ALARA to non-radiation work health hazards and have changed the term to As Low As Is Reasonably Practicable. Byrant et al. (2017) reasons that the terms “achievable” and “practicable” are in practice the same. Other assessment approaches include Best Available Technology. These processes use multi-criteria decision frameworks similar to the ERA BPT assessment. A further similarity between ALARA and BPT is the common phrase about considering economic and social factors.

ERA has researched and documented a process for the application of ALARA with respect to non-radiological hazards to demonstrate that environmental impacts on the RPA and exposure to chemical pollutants are ALARA. The process (Appendix 6.2) adopts recommendations from the international literature to implement an holistic framework that combines options and risk assessments to derive and demonstrate an ALARA outcome. The process can also consider options that would result in levels of contamination in the riparian zones that are as low as technically possible.

This holistic ALARA process was developed in consultation with stakeholders. Discussions with the NLC and GAC regarding ALARA and the process are continuing. This will help refine the process for application.

6.4 Future BPT assessments

BPT assessments will be held for all future applications, and where any other further decisions on technology arise. Such planned applications include Pit 3 closure, TSF deconstruction and the final landform

6.5 References

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APPENDIX 6.1: BEST PRACTICABLE TECHNOLOGY ASSESSMENT MATRICES

BPT assessment matrix for North Notch 3

						Protection of People and the Environment			Fit for Purpose				
			Show stopper column setting			Yes	No	Yes	No	No		Yes	No
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
	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

BPT assessment matrix for North Notch 3 *continued*

						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

BPT assessment matrix for TSF subfloor material management

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						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

BPT assessment matrix for TSF subfloor material management *continued*

						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

BPT assessment matrix for TSF subfloor material management *continued*

						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

BPT assessment matrix for TSF subfloor material management *continued*

						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

BPT assessment matrix for treatment of low solute process water (high density sludge plant recommissioning)

					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

BPT assessment matrix for treatment of low solute process water (high density sludge plant recommissioning) *continued*

					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

BPT assessment matrix for treatment of low solute process water (high density sludge plant recommissioning) ***continued***

					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

BPT assessment matrix for tailings deposition options for Ranger Pit 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

BPT assessment matrix for tailings deposition options for Ranger Pit 3 *continued*

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

BPT assessment matrix for tailings deposition options for Ranger Pit 3 *continued*

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

BPT assessment matrix for tailings deposition options for Ranger Pit 3 *continued*

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

BPT assessment matrix for brine minimisation

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

BM Brine Minimisation

					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
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
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

BPT assessment matrix for brine minimisation *continued*

BM	Brine Minimisation	Rehabilitation and Closure							Constructability		
		Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
		1	1	1	1	1	1	1	1	1	1
Option ID	Option Description	Revegetation	Radiation	Erosion	Water Quality	Tailings	Schedule	Cost	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction Complexity
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

BTP assessment matrix for blackjack waste disposal

						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										

BTP assessment matrix for Ranger 3 Deeps

						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				

BTP assessment matrix for Ranger 3 Deeps *continued*

						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

BTP assessment matrix for Ranger 3 Deeps *continued*

						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								

BTP assessment matrix for Ranger 3 Deeps *continued*

						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
	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

BTP assessment matrix for Ranger 3 Deeps *continued*

						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
	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

BTP assessment matrix for Ranger 3 Deeps *continued*

						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

BTP assessment matrix for ITWC prefeasibility study

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

BTP assessment matrix for ITWC prefeasibility study *continued*

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

BTP assessment matrix for ITWC prefeasibility study *continued*

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

BPT assessment matrix for supplementary assessment - tailings treatment

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

BPT assessment matrix for supplementary assessment - tailings treatment *continued*

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

					Fit for Purpose					Operational Adequacy				
		Show stopper column setting			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

BPT assessment matrix for supplementary assessment - tailings treatment *continued*

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

					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
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

APPENDIX 6.2: ALARA & BPT FOR RANGER MINE CLOSURE

ERA Energy Resources of Australia Ltd

ALARA & BPT for Ranger mine closure

The process for identifying if impacts on the Ranger Project Area after closure are as low as reasonably achievable.

Author(s): Michelle ILES

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APPENDICES

APPENDIX 1: DOE (2000) CHAPTER C STATUTORY GUIDANCE ON THE REMEDIATION OF CONTAMINATED LAND: PART 5 THE REASONABLENESS OF REMEDIATION

EXECUTIVE SUMMARY

The Commonwealth Environmental Requirements (ERs) for closure of Ranger mine include: possible incorporation of the site into Kakadu National Park; onsite (i.e. within the Ranger Project Area) impacts that are as low as reasonably achievable (ALARA); and, protection of the people, ecosystem, and World Heritage and Ramsar wetland values of the surrounds. To comply with the ERs, the closure of the Ranger mine must be implemented in accordance with Best Practicable Technology (BPT) process described in the ERs.

In addition to requiring impacts on the RPA that are ALARA, the term ALARA also applies to:

- exposure of Aboriginals and other members of the regional community to radiation and chemical pollutants to (1.2c),
- radiation health risks to members of the public (2.2b)
- radiation protection of workers and the public (ER5), impacts on the RPA from hazardous materials and waste (ER 6) and management of excavated material (ER 7).

Traditional Owners have expressed an expectation that rehabilitation in the riparian zones is *as high as is technically possible and level of contamination must be as low as technically possible.*

The ALARA concept comes from the field of radiation protection. ALARA and “optimisation of protection” are interchangeable in International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) documents (IAEA 2010). Several countries have extended the concept of ALARA to non-radiation work health hazards and have changed the term to As Low As Is Reasonably Practicable (ALARP). The terms “achievable” and “practicable” are in practice the same and are widely accepted as such. Other assessment approaches include Best Available Technology (BAT). All have similarities with the ERA BPT approach.

The ALARA procedure is a stepwise options assessment process followed to arrive at an option that represents the most acceptable result. It is not driven by numeric values. The quality achieved with the chosen option is ALARA.

ALARA is a top down approach to risk assessment compared to pollution/environmental risk control as a bottom up approach. Nga et al (2000), who discuss the opposing philosophies of ALARA and pollution risk control, and numeric targets versus ALARA, say:

> *The current framework for managing public exposures to chemical carcinogens has been referred to as a “bottom up approach.” Risk is typically evaluated for each source and an acceptable risk range …, is established. The lower risk of this range is then established as an “upper bound” goal. Risk managers seek to achieve protection at the “upper bound” goal by limiting exposure or removing the environmental contamination. If this goal is not achievable after the considerations of technical feasibility, cost, and other factors, the risk manager may decide to accept a “lower bound” goal within the risk range that could lead to a less stringent level of protection.*

The top-down strategy involves aggregating risks from all sources and setting an upper bound dose limit, then using the ALARA principle to reduce the risk.

The water quality objectives adopted by SSB as rehabilitation standards for water leaving the RPA are an example of numerical risk targets. These guideline values will protect the ecosystem from any change to biodiversity which is the management goal for outside the RPA. The management goal for on the RPA is impacts that are ALARA. The numerical risk targets set for high level ecosystem protection can be exceeded and a less stringent level of protection accepted if it can be shown that the lower bound is what is achievable after considering multiple criteria such as the technical feasibility, cost and other factors, ie is ALARA.

Nga et al (2000) recommend a flexible risk management framework and assessing multiple or cumulative risks as an approach to dealing with both the top down ALARA approach, and the bottom up numeric values approach. Bryant et al (2017), describes an holistic framework to undertake such a combined options-risk assessment to derive an ALARA outcome.

Adopting the approach demonstrated by Bryant et al (2017), a BPT assessment coupled with ERA's risk management processes can be used to identify closure options that provide an ALARA outcome.

The issue of weighting different criteria to demonstrate the sensitivity of cultural criteria against costs was requested by the Traditional Owners and can be implemented with the BPT assessment tool. This will provide information to support discussions on what is reasonable; a decision that will be made through discussions in the appropriate forums. Information is provided in this document to support discussions on the issue of what is reasonable, and points given on how the BPT assessment tool can be used to weight different assessment criteria to inform these discussions.

1 BACKGROUND

The Ranger uranium mine (Ranger/Ranger mine) is located within the Ranger Project Area (RPA) adjacent to Jabiru, approximately 260 kilometres east of Darwin in the Alligator Rivers Region of the Northern Territory. The RPA is surrounded by Kakadu National Park (KNP), and is bounded on the east and north by Magela Creek and its tributaries, and on the west by Gulungul Creek and its tributaries. Access to the mine is via the Arnhem Highway.

Energy Resources of Australia Ltd (ERA) has owned and operated the Ranger mine since the commencement of operations in 1980.

Under the current operational approvals, ERA is required to cease mining and milling operations by 8 January 2021, with final rehabilitation and closure activities completed by 8 January 2026.

The operation and closure of Ranger mine must be conducted in accordance with the Commonwealth Environmental Requirements.

1.1 Environmental Requirements

The Commonwealth Environmental Requirements (ERs) for Ranger, appended to the section 41 Authority, set out environmental objectives which establish the principles by which the Ranger Mine operation is to be conducted, closed and rehabilitated and the standards that are to be achieved. The *Mining Management Act* also requires the Ranger Authorisation to incorporate, by reference, the ERs. The ERs were revised in 1999 to be inclusive of conditions relating to rehabilitation (Commonwealth of Australia 1999).

The ERs specify primary and secondary environmental objectives.

The Primary Environmental Objectives are:

- Protection of the people, ecosystem (biodiversity and ecological processes), and World Heritage and Ramsar values of the surrounds (ER 1 and 2),
- As Low As Reasonably Achievable (ALARA) environmental impacts on the RPA (ER 1.2e)
- ALARA exposure of Aboriginals and other members of the regional community to radiation and chemical pollutants to (1.2c),
- ALARA radiation health risks to members of the public (2.2b)

The Secondary Environmental Objectives state that:

- Water from site must not jeopardise the Primary Environmental Objectives (ER 3.1)
- The RPA must be returned to a state in which it could be incorporated into Kakadu National Park (ER 2.1)
- All aspects of the Ranger ERs must be implemented in accordance with Best Practicable Technology (ER 12.1).

- ALARA is required for radiation protection of workers and the public (ER5), impacts on the RPA from hazardous materials and waste (ER 6) and management of excavated material (ER 7).

The Supervising Scientist Branch interprets BPT as the technology that is consistent with achieving the primary environmental requirements and ranks highest when considering world's best practice, cost-effectiveness, proven effectiveness, Ranger's location, the age of equipment and social factors (Supervising Scientist 2001).

ALARA is well defined and practiced in the world of radiation protection. There is a need to understand its application with respect to non-radiological hazards to demonstrate that environmental impacts on the RPA and exposure to chemical pollutants are ALARA.

1.2 Traditional Owner expectations

This document discusses the regulatory requirement for impacts on the RPA that are ALARA, and processes and frameworks for determining what ALARA is.

While this is necessary, it is important to note that Traditional Owners reported concerns with trying to integrate cultural values within 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).

Garde (2015) also expressed the views of the Traditional Owners on ALARA and BPT stating "*…the waters contained within all riparian corridors, (i.e. rivers and billabongs), must be of a quality that is commensurate with non-affected riverine systems and health standards. The principle of 'as low as reasonably achievable' should not apply to these areas. Instead, the standard of rehabilitation must be as high as is technically possible and level of contamination must be as low as technically possible.*"

The Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC) reiterated this and provided additional (draft) information on their position on ALARA for onsite water bodies (email from Chris Brady 8/4/2020).

> *In the response to the 2019 Mine Closure Plan draft, the Traditional Owner representatives emphasise the importance of waterways on the RPA to traditional owners. These areas were previously, and should again be, a focus of activity for traditional owners. The main focus of activity is likely to be focussed on Georgetown and Coonjimba Billabongs and the Magela Creek channel.*
>
> *The principle of "as low as reasonably achievable" therefore should not apply to these areas. Instead, the standard of rehabilitation must be as high as is technically possible and the level of contamination must be as low as technically possible.*
>
> *In recognition of this, the BPT process established by ERA for determining water quality of these key waterbodies is adjusted such that cost is not considered, whilst the weighting of cultural value is doubled.*
>
> *Additionally, to ensure that the aim is for these key waterways to be utilised by traditional owners, for example as seasonal camping area where people fish and come into contact*

with the water, the water quality at an absolute minimum, will not exceed the Australian recreation water quality guidelines as a result of mine related activities.

In other water bodies (e.g. sumps, minor drainage lines) traditional owners expect that management during the monitoring and maintenance period pending final rehabilitation will be such that they do not pose a credible risk to people or wildlife.

A final NLC/GAC position paper is in preparation.

The information in this document, while aimed at clarifying how to determine what impacts are ALARA, can also provide a starting point for how the process can be adapted to consider the expectations of the traditional owners, particularly with respect to the riparian zones.

2 ALARA

ALARA is the acronym standing for 'As Low As Reasonably Achievable', used to define the principle underlying optimization of radiation protection: radiation exposure must be kept as low as reasonably achievable, taking economic and social factors into account. ALARA for radiation protection is integrated into national regulations globally. Regulations will vary from country to country, but will contain requirements on optimisation and on how to achieve ALARA (IAEA, 2010).

ALARA and "optimisation of protection" are interchangeable in ICRP and IAEA documents. (IAEA 2010). In the latest Recommendations (ICRP, 2007), the acronym ALARA is not used; optimisation of protection is used instead.

The objective of optimisation is to achieve an appropriate balance between the efficient use of protection resources and the risks.

ICRP Publication 103 (ICRP, 2007) defines optimization of protection (and safety) as *the process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, as low as reasonably achievable, economic and societal factors being taken into account.*

Several countries have extended the concept of ALARA to non-radiation work health hazards and have changed the term to As Low As Is Reasonably Practicable (ALARP). Byrant et al 2017 reasons that the terms "achievable" and "practicable" are in practice the same and are widely accepted as such.

2.1 ALARA versus numerical risk targets

The issue of ALARA as a top down approach to risk assessment, compared to pollution/environmental risk control as a bottom up approach has long been acknowledged (eg Domotor et al 1999, Nga et al 2000)

Nga et al (2000) discuss the opposing philosophies of numerical risk targets versus the ALARA principle:

The current framework for managing public exposures to chemical carcinogens has been referred to as a "bottom up approach." Risk is typically evaluated for each source and an *acceptable risk range …, is established. The lower risk of this range is then established as an "upper bound" goal. Risk managers seek to achieve protection at the "upper bound" goal by limiting limiting exposure or removing the environmental contamination. If this goal is not achievable after the considerations of technical feasibility, cost, and other factors, the risk manager may decide to accept a "lower bound" goal within the risk range that could lead to a less stringent level of protection.*

In contrast, a "top down" approach that sets an upper bound dose limit and couples with site specific As Low As Reasonably Achievable Principle (ALARA), is in place to manage individual exposure to radiation. While radiation risk are typically managed on a cumulative basis, exposure to chemicals is generally managed on a chemical-by-chemical, medium-by-medium basis.

In contrast, the dominant framework for managing individual radiation exposures has been described as a "top down" approach. The top-down strategy involves aggregating risks from all sources and setting an upper bound dose limit, then using the ALARA principle to reduce the risk.

The water quality objectives adopted by SSB as rehabilitation standards for water leaving the RPA are an example of numerical risk targets. These guideline values will protect the ecosystem from any change to biodiversity which is the management goal for outside the RPA. The management goal for on the RPA is impacts that are ALARA. The numerical risk targets set for high level ecosystem protection can be exceeded and a less stringent level of protection accepted if it can be shown that the lower bound is what is achievable after considering multiple criteria such as the technical feasibility, cost and other factors, ie is ALARA.

ALARA is a top down approach where a dose limit is derived which cannot be exceeded and a process is followed for pushing exposures even lower. (It also includes setting a dose constraint as a target and trying to keep below that.)

These two approaches are based on opposite philosophies. Nga et al (2000) recommend a flexible risk management framework and assessing multiple or cumulative risks as an approach to incorporating both issues.

The following sections show how this can be achieved through coupling the ALARA procedure, which includes an options assessment process, the BPT tool as the options assessment matrix and ERA's risk management system.

2.2 The ALARA procedure

The ALARA procedure is a stepwise options assessment process followed to arrive at an option that represents the most acceptable result rather than a process to derive a numeric values. The quality achieved with the chosen option is ALARA as indicated by the following statements:

EAN (2019), citing ICRP Publication 101 (ICRP, 2006), says *ALARA is an obligation of means, and not an obligation of results, in the sense that the result of ALARA depends on processes, procedures, and judgements and is not a given value of exposure.*

Successful optimisation focuses on the effective use of robust processes to evaluate situations rather than on specific numerical results (NEA & CRPPH, 2012).

ALARA, as applied by DOE, is not a numerical level or limit, but rather a process which is to be used to ensure that appropriate factors are taken into consideration in arriving at decisions (Domotor et al, 1999).

This is demonstrated by Figure 1 (taken from Oudiz et al, 1986) which shows that ALARA is the result achieved by selection of the best option.

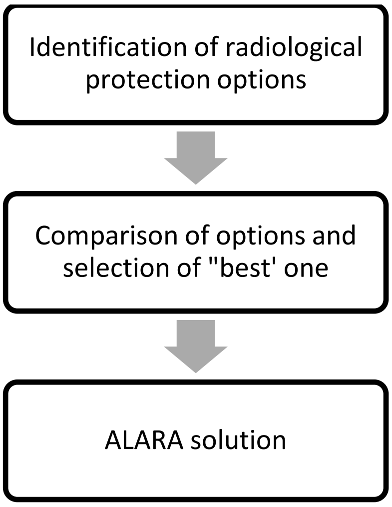

Figure 1 The main features of the ALARA procedure (Oudiz et al. 1986)

IAEA (2010) states *An ALARA approach may identify the need for an ALARA study of a specific situation. The study may include the following steps (see also European Commission "ALARA from theory to practice", report EUR 13796, 1991[1]):*

- Define the problem,
- Make a preliminary analysis of the type and level of doses,
- Define the radiation protection options,
- Quantify, where possible, the impact of these options in terms of cost, dose, time, etc. For some factors a qualitative assessment may be necessary
- Compare the options,
- Make a sensitivity analysis,
- Select and implement an optimized solution.

EAN (2019) reviewed and updated the European Commission report cited above and say that the basic steps remain the same.

[1] Listed in the Reference section of this report as Lochard et al (1991).

2.3 Applying the ALARA procedure to non-radiological hazards

Bryant et al (2017) discusses the work and ALARA procedure cited by IAEA (2010) above describing the ALARA procedure as being **generic and applicable to radiological and non-radiological hazards.** They modified the steps of the ALARA procedure referred to above to sit within a framework for an holistic assessment of multiple hazards (Figure 2) and used it to demonstrate they had reduced radiological and non-radiological hazards and risks to ALARA/ALARP.

The steps in the framework in Figure 2 are discussed below in terms of how they are, or could be applied, by ERA to demonstrate that:

- if the closure strategy, and aspects of it, are consistent with Best Practical Technology (BPT) and are supported by a sound risk management system, then
- the resulting (predicted or measured) environmental impacts, and chemical and radiation exposure to members of the public are ALARA.

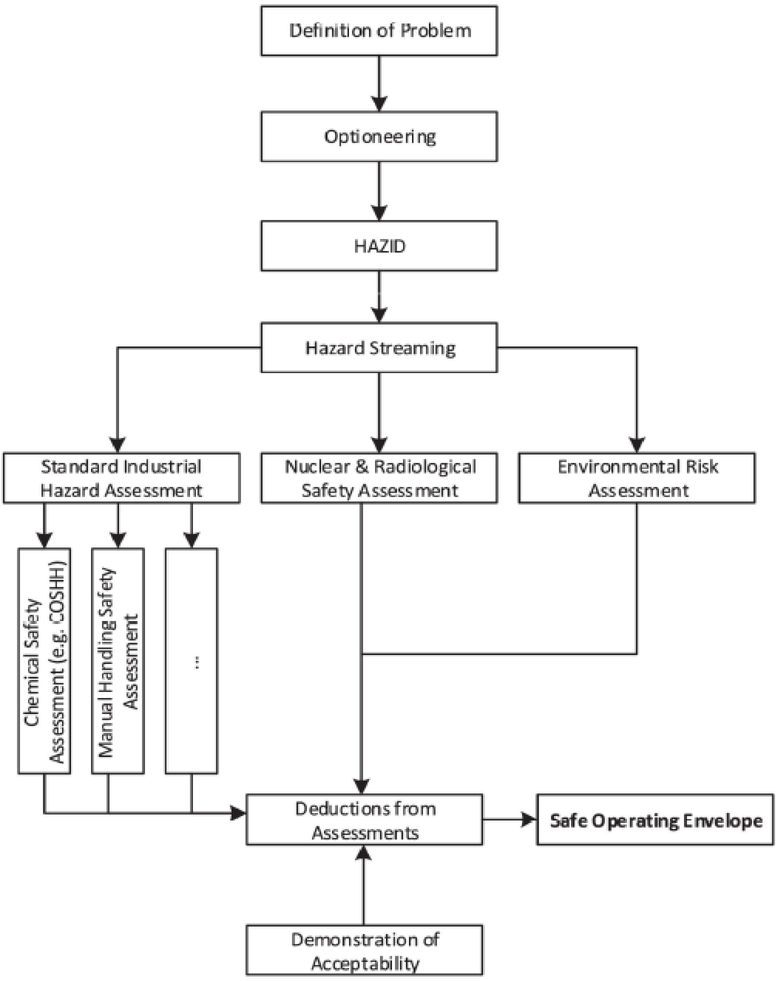

Figure 2 Framework for the integration of risks from multiple hazards into a Holistic ALARA/ ALARP demonstration (from Bryant et al 2017).

2.3.1 Steps 1 & 2: Problem definition and Optioneering

Bryant et al (2017) state that the first two steps *Problem definition* and *Optioneering lay the foundation to the ALARP argument. First there must be a clear definition of the problem, and then an optioneering assessment to identify possible solutions to the problem and select a preferred option or options.*

2.3.1.1 Problem definition

The clear definition of the problem is usually the activity that ERA is seeking approval for. There are several options for implementing these activities and these options are assessed. The problem will be described during the initial stage of the options assessment. This will all be described in the application for approval of the activity.

2.3.1.2 Optioneering

IAEA 2010 identifies cost-benefit analysis, cost-effectiveness analysis and multi-criteria decision analysis as useful decision-aiding tools for implementing ALARA.

Cost benefit analysis is useful in radiation protection where costs per unit of radiation dose protection are well established. However only costs and doses are analysed, other important factors such as social factors are ignored. Multi-criteria decision analysis is preferable as it can focus on multiple attributes and use a scoring scheme that can accommodate qualitative and linear or non-linear quantitative data. ICRP (1990) recommends multi-criteria decision analysis.

In radiation protection the ALARA approach is used to optimise radiation doses, whereas the “Best Available Technique” (BAT) approach is used to ensure effluent releases from a source are appropriately controlled. Both are considered optimisation techniques and can be complimentary to each other. The phrase “best available techniques” tends to be used more often in western Europe, whereas the term “optimisation” is used more globally. (NEA & CRPPH, 2012).

Other terms with similar meaning are also used in effluent management, such as Best Practicable Environmental Option (BPEO) and Best Practicable Means (BPM) (Bryant et al 2017). These concepts apply to water, air, and soil and can be extended to general environmental protection.

BAT is identified through evaluating the trade-off between what can done to reduce discharges and what is a reasonable (or unreasonable) cost to pay for that reduction. The term “reasonable” requires an inherent value judgement to be made with social and ethical concerns to be factored in and may differ for different countries. (See Section 3 for a discussion on reasonable.)

To comply with the ERs, the closure of Ranger must be implemented in accordance with Best Practicable Technology (BPT). BPT is similar to BAT and can be applied to issues broader than effluent management. Like BAT, BPT is tool for optimising technologies and strategies adopted by ERA for the Ranger site.

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 (SSD, 2001). In considering the best procedure for ensuring that the BPT concept became a driver for identifying the best 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 remain consistent with the original six broad matters in the formal definition of BPT.

Bryant et al (2017) list the following six key steps in an optioneering assessment; dot points at each step show the similarity to the ERA BPT process.

I. Define requirements (e.g. functional requirements that must be met by the solution).
   - This is the technical objective of the BPT

II. Identify options
   - The alternative options being assessed in the BPT analyses. The selection of these options are supported by site-specific requirements, studies and recommendations from industry experts.

III. Define selection criteria-Assurance (including radiological safety, conventional safety, and environmental risks), engineering, business, etc
   - These are described in the BPT scoring matrix which also includes assessment criteria for Culture & Heritage and themes linked to the Environmental Requirements for closure. Different weights can be assigned to different categories to ensure protection of more highly valued aspects. This would need to be agreed by stakeholders.

IV. Analyse options-Assess against criteria
   - This is the BPT assessment.

V. Scoring and ranking-Rank the options based on the assessment of the options
   - The BPT assessment process compares different management options and ranks them against each other based on scores for each of the BPT criteria.

VI. Down selection-Identify preferred option(s)
   - All scores are combined to a single value and the different options ranked. The option with the best score is deemed to be BPT.

2.3.2 Steps 3 & 4: Hazard determination and streaming

Hazards are identified for the preferred option and allocated to an assessment stream based on type of hazard (eg nuclear/ radiological, industrial or environmental) and level of risk. The hazards are then assessed in an approach proportionate to the hazard/risk. (Bryant et al 2017). This agrees with advice from international bodies who say optimisation of protection is not only about choosing the best options, those options need to be implemented effectively meaning management systems have an important role in effectively implementing the ALARA and BAT concepts (NEA & CRPPH, 2012).

ERA has a mature HSE management system in place that is certified to ISO14001:2016 and AS4801:2001. This includes numerous individual management plans related to protecting the environment and human health and covering topics including, but not limited to, water, tailings, weeds, radiation, occupational health, culture and heritage, hazardous materials, mineralised material, waste management etc.

The ERA HSE Management System is designed along the principles of continuous improvement and generally follows the layout of the Plan, Do, Check, and Review cycle which is common to many international standards. The scope of its HSE MS includes the mining, processing and rehabilitation of uranium ore resources at the Ranger Mine including maintenance and ancillary services.

This system assists ERA to comply with internal and external commitments, demonstrates a system of continual improvement in operational performance and assists ERA in achieving environment, safety and health excellence.

The approach ERA has taken to risk assessment has been developed to identify hazards, aspects and opportunities in advance of project or activity implementation. The resulting risks and impacts to the business, people, property, assets and the environment are recorded and evaluated, and strategies are developed to manage them. The framework is consistent with recognised Australian standards and corporate management standards and practices including AS ISO 31000:2018 Risk Management – Principles and guidelines, AS/NZS ISO 14001 Environmental Management Systems and internal Rio Tinto and ERA standards and commitments.

During the Ranger Mine closure feasibility study, a series of risk assessment workshops were completed to further develop the Ranger closure risk register. These were conducted in accordance with the ERA hazard identification and risk management standard (ERA 2018) and the *Rio Tinto HSEC-C-01 HSEC Risk Assessment Group Procedure*.

In June 2019 the environmental risk assessment published in the 2018 Ranger mine closure plan (MCP) was updated with the outcomes of the feasibility study risk assessment and to consider the comments received from the Supervising Scientist on the 2018 MCP risk section.

Section 10 of the 2019 MCP (ERA 2019) presents a summary of the ERA approach to closure related risk assessment and the outcomes of the then most recent closure risk assessment. Outcomes from more recent risk assessments will continue to be reviewed and additional risks identified during internal or external workshops (e.g. the cumulative risk assessment currently being run by Supervising Scientist Branch (SSB)) will be considered in future iterations of the Ranger MCP.

2.3.3 Step 5: Deductions and safe operating envelope

Bryant et al 2017 go on to say *The output of the various assessments should be reviewed in combination, to ensure that there are no conflicts, for instance any controls or mitigations put* *in place for one hazard type have not created any new hazards, or impacted any of the other hazard assessments. These deductions are then used to define the Safe Operating Envelope (SOE). This review should be undertaken by a SQEP panel, who have a demonstrable understanding of the various hazard types. The SOE includes any bounding conditions, engineered and/ or managerial safety controls (and requirements placed on the controls, including maintenance), which are to be implemented by the facilities safety management arrangements. Where the bounding conditions are key physical parameters which inform the facilities of specific limits of safe operation, for instance, limits on the quantities of hazardous materials that may be present in a facility.*

Assessment of risks has been ongoing at Ranger for several decades and resulted in strict operational requirements and a large number of environmental and engineering studies over the years.

The risk management approach adopted for the Ranger Closure Project is one of integrated and iterative risk identification and assessment processes applied as inputs to key project stages and activities. All key risks relevant to the project are in a single risk register, with risks owned by ERA and the Project team members as required to ensure effective management of risks and implementation of risk treatment plans. Separate registers exist to cover the HAZID / HSEC risks and technical risk which are managed via the engineering management plan.

This approach contributes to a holistic application of risk management techniques across all risk areas including strategic, technical, commercial, safety and environmental that meets the intent of ERA and Rio Tinto project risk management protocols while providing a best-for-project risk management solution.

Change management procedures are followed for mitigations being introduced, and representation of multiple working groups and disciplines in risk assessments reduce the potential for conflicts with risk mitigation. Major projects undergo internal and external review by teams of subject matter experts doing deep dives into identified risks and management strategies. Strategies and mitigations plans form part of applications assessed by stakeholders.

There has also been ecological risk assessments for the closure of Ranger which lead to the review of the Key Knowledge Needs for closure. Research projects are being conducted by ERA and SSB to address these. Many of these studies result in safe operating envelopes.

Some examples of safe operating envelopes for the closure of Ranger include:

- Targets for consolidation of tailings, limits on the level of tailings placed in pits, and targets for extraction and treatment of pit tailings flux, and process water.
- Limits for water quality at the lease boundary, and for treatment plant discharges.
- Maximum operating level for process water in Pit 3 and the TSF and maximum drawdown rates in the TSF.
- Waste segregation, ie rock grade control and burial of higher grades at depth.
- Closure criteria.

- Engineered and/ or managerial safety controls (and requirements placed on the controls, including maintenance) identified in the Ranger Closure Feasibility study.
- Shaping of landform based on landform evolution studies.
- Thickness of cover for radiation protection and plant available water.
- Tailings buried for 10,000 years.
- Critical controls, SOPS, and accredited management systems.

2.3.4 Step 6: Demonstration of acceptability

The final step is demonstration of acceptability. Assumptions underpinning the hazard/risk assessment need to be substantiated to demonstrate that they can be met. *The extent of substantiation should be proportionate to the level of risk reduction and confidence required for the safety measure. This may range from compliance with relevant standards, to a more in-depth assessment of failure modes or through life limiting factors.* (Bryant et al 2017).

This is achieved at ERA through the large body of research and studies that are undertaken (as part of Rio Tinto feasibility studies, ongoing technical studies to implement the closure strategy, and to address key knowledge needs for protection of the ecosystem during operations, closure and post closure) and applications for approval for major activities and the annual Mine Closure Plan. These studies and applications are peer reviewed through a number of stakeholder committees.

Relevant standards for the closure of Ranger mine include the SSB rehabilitation standards and ERA closure criteria which are based generally on the ERs and specifically on national regulations and guidelines, eg radiation dose limits, dietary standards, local and default water quality guideline values.

Predictive modelling is used to demonstrate that the closure strategy will result in compliance with relevant standards. Reports on these models contain sensitivity assessments and are peer reviewed. Examples of such models are:

- Derivation of water quality standards based on ecotoxicological models
- Solute transport models.
- Landform stability and erosion models.
- Tailings consolidation models.
- Plant available water models.
- Models of ecosystem establishment trajectories.
- Radiation dose assessments.

Measurements of contaminants and remediation plans are also peer reviewed.

Discussions of the risks, options and BPT assessments, supporting studies, mitigations and monitoring form part of each application submitted for approval for key closure activities. The applications and processes described in the applications are in effect the same as the safety case demonstrating ALARA/ALARP described by Bryant et al 2017.

3 REASONABLENESS

Agreeing on what is reasonable will involve all stakeholders working together to discuss their different views and expectations. This will be dealt with through the relevant stakeholder committees; eg Ranger Minesite Technical Committee, Relationship Committee. Some information is provided here to provide some working points and references for those groups.

In the UK, the statutory guidance to Part IIA of EPA 1990 (Chapter C, DETR Circular 02/2000) sets out very specific criteria for the identification of Best Practicable Technique for the determination of appropriate remediation requirements.

Part 5 The Reasonableness of Remediation (provided in Appendix 1) provides guidance on the determination by the enforcing authority of what remediation is, or is not, to be regarded as reasonable having regard to the cost which is likely to be involved and the seriousness of the harm or of the pollution of controlled waters to which it relates.

Advise on cost and reasonableness

The advice is that a remediation action is reasonable if the cost assessment shows benefits justifying the cost. The benefits to consider are the resulting from the contribution that the action makes, either on its own or in conjunction with other remediation actions, to:

> (a) reducing the seriousness of any harm or pollution of controlled waters which might otherwise be caused; or
>
> (b) mitigating the seriousness of any effects of any significant harm or pollution of controlled waters.

A necessary condition of an action being reasonable is that there is no alternative scheme which would achieve the same purposes or standard of remediation for a lower overall cost (bearing in mind that the purpose of any remediation action may relate to more than one significant pollutant linkage).

Such an assessment should include the preparation of an estimate of the costs likely to be involved and of a statement of the benefits likely to result. This latter statement need not necessarily attempt to ascribe a financial value to these benefits.

The BPT assessment framework for assessing different options for remediation activities considers the environmental outcome and costs associated costs with each option/mitigation strategy[2].

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[2] Note; costs in future BPT assessments don’t consider the many mitigation strategies that have already been adopted to reduce risks associated with mine closure; for example; waste segregation, tailings burial, pond and process water treatment, placement of reactive materials at depth, wick placement and tailings deposition methods to accelerate tailings consolidation, etc.

Advise on environmental harm and reasonableness

The advice on evaluating the seriousness of environmental harm for the purposes of assessing the reasonableness of any remediation, should include consideration of:

(a) whether the significant harm is already being caused;

(b) the degree of the possibility of the significant harm being caused;

(c) the nature of the significant harm with respect, in particular, to:

(i) the nature and importance of the receptor,

(ii) the extent and type of any effects on that receptor of the significant harm,

(iii) the number of receptors which might be affected, and

(iv) whether the effects would be irreversible; and

(d) the context in which the effects might occur, in particular:

(i) whether the receptor has already been damaged by other means and, if so, whether further effects resulting from the harm would materially affect its condition, and

(ii) the relative risk associated with the harm in the context of wider environmental risks.

Much of this will be considered in the BPT assessment itself. Useful reports for interpreting the results of the BPT and studies informing it in the context of the above suggestions include, for example:

- BMT (2018, 2019) reports on indicators for primary environmental objectives, environmental values of water on and off the RPA, descriptions of drivers of ecosystem stress, ecosystem component characteristics and vulnerability (which includes reversibility and implications of exposure characteristics such as duration, intensity, seasonality etc.).
- SSB reports on biological effects of contaminants and monitoring results.
- Relative risks from mining compared to landscape scale risks such as weeds, feral animals, climate change etc. (eg Bayliss et al 2012, 2015, 2016; Humphrey et al 2016).
- Climate change predictions for the region (will be reported as part of the current ERA closure climate change assessment).
- Reports on the Kakadu National Park environment (eg BMT, 2010).

4 CONCLUSIONS

ERA's practices and procedures for options assessments and risk management and mitigation are aligned with the ALARA procedure.

Considering the terms ALARA and optimisation of protection are interchangeable, and that choosing the best technology is a form of optimisation (NEA & CRPPH, 2012), BPT is therefore a tool for identifying the ALARA solution, and is the tool ERA must use to do this according to both the ERs and the Ranger Authorisation.

Therefore, ERA proposes the option that is considered BPT represents the best option of achieving impacts that are ALARA. However, the final decision on what is reasonable needs to be agreed between stakeholders through the relevant committees.

Some information that may assist those discussions in provided in this document. Also, the BPT process can include weighting of different assessment aspects/criteria which means the BPT tool can be adjusted to test the sensitivity of the different options, or aspects of an option, to different assessment criteria (eg Cultural and heritage values, cost, time, safety). This will provide information to help the stakeholders come to an agreement on what is ALARA.

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C.29 The statutory guidance in this Part is issued under section 78E(5)(c) and provides guidance on the determination by the enforcing authority of what remediation is, or is not, to be regarded as reasonable having regard to the cost which is likely to be involved and the seriousness of the harm or of the pollution of controlled waters to which it relates.

C.30 The enforcing authority should regard a remediation action as being reasonable for the purpose of section 7 8E(4) if an assessment of the costs likely to be involved and of the resulting benefits shows that those benefits justify incurring those costs. Such an assessment should include the preparation of an estimate of the costs likely to be involved and of a statement of the benefits likely to result. This latter statement need not necessarily attempt to ascribe a financial value to these benefits.

C.31 For these purposes, the enforcing authority should regard the benefits resulting from a remediation action as being the contribution that the action makes, either on its own or in conjunction with other remediation actions, to:

(a) reducing the seriousness of any harm or pollution of controlled waters which might otherwise be caused; or

(b) mitigating the seriousness of any effects of any significant harm or pollution of controlled waters.

C.32 In assessing the reasonableness of any remediation, the enforcing authority should make due allowance for the fact that the timing of expenditure and the realisation of benefits is relevant to the balance of costs and benefits. In particular, the assessment should recognise that:

(a) expenditure which is delayed to a future date will have a lesser impact on the person defraying it than would an equivalent cash sum to be spent immediately;

(b) there may be a gain from achieving benefits earlier but this may also involve extra expenditure; the authority should consider whether the gain justifies the extra costs. This applies, in particular, where natural processes, managed or otherwise, would over time bring about remediation; and

(c) there may be evidence that the same benefits will be achievable in the foreseeable future at a significantly lower cost, for example, through the development of new techniques or as part of a wider scheme of development or redevelopment.

C.33 The identity or financial standing of any person who may be required to pay for any remediation action are not relevant factors in the determination of whether the costs of that action are, or are not, reasonable for the purposes of section 78E(4). (These factors may however be relevant in deciding whether or not the enforcing authority can impose the cost of remediation on that person, either through the service of a remediation notice or through the recovery of costs incurred by the authority; see (section 78P and the guidance in Chapter E.)

The Cost of Remediation

C.37 The enforcing authority should furthermore regard it as a necessary condition of an action being reasonable that:

(a) where two or more significant pollutant linkages have been identified on the land in question, and the remediation action forms part of a wider remediation scheme which is dealing with two or more of those linkages, there is no alternative scheme which would achieve the same purposes for a lower overall cost; and

(b) subject to subparagraph (a) above, where the remediation action forms part of a remediation package dealing with any particular significant pollutant linkage, there is no alternative package which would achieve the same standard of remediation at a lower overall cost.

C.38 In addition, for any remediation action to be reasonable there should be no alternative remediation action which would achieve the same purpose, as part of any wider remediation package or scheme, to the same standard for a lower cost (bearing in mind that the purpose of any remediation action may relate to more than one significant pollutant linkage).

The Seriousness of Harm or of Pollution of Controlled Waters

C.39 When evaluating the seriousness of any significant harm, for the purposes of assessing the reasonableness of any remediation, the enforcing authority should consider:

(a) whether the significant harm is already being caused;

(b) the degree of the possibility of the significant harm being caused;

(c) the nature of the significant harm with respect, in particular, to:

(i) the nature and importance of the receptor,

(ii) the extent and type of any effects on that receptor of the significant harm,

(iii) the number of receptors which might be affected, and

(iv) whether the effects would be irreversible; and

(d) the context in which the effects might occur, in particular:

(i) whether the receptor has already been damaged by other means and, if so, whether further effects resulting from the harm would materially affect its condition, and

(ii) the relative risk associated with the harm in the context of wider environmental risks.

C.40 Where the significant harm is an "ecological system effect" as defined in Chapter A, the enforcing authority should take into account any advice received from English Nature.

C.41 In evaluating for this purpose the seriousness of any pollution of controlled waters, the enforcing authority should consider:

(a) whether the pollution of controlled waters is already being caused;

(b) the likelihood of the pollution of controlled waters being caused;

(c) the nature of the pollution of controlled waters involved with respect, in particular, to:

(i) the nature and importance of the controlled waters which might be affected,

{ii) the extent of the effects of the actual or likely pollution on those controlled waters, and

(iii) whether such effects would be irreversible; and

(d) the context in which the effects might occur, in particular:

(i) whether the waters have already been polluted by other means and, if so, whether further effects resulting from the water pollution would materially affect their condition, and

(ii) the relative risk associated with the water pollution in the context of wider environmental risks.

C.42 Where the enforcing authority is the local authority, it should take into account any advice received from the Environment Agency when it is considering the seriousness of any pollution of controlled waters.

C.43 In some instances, it may be possible to express the benefits of addressing the harm or pollution of controlled waters in direct financial terms. For example, removing a risk of explosion which renders a building unsafe for occupation could be considered to create a benefit equivalent to the cost of acquiring a replacement building.

Various Government departments have produced technical advice, which the enforcing authority may find useful, on the consideration of non-market impacts of environmental matters.