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Using bow-ties to provide a clear and transparent mine closure plan

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Abstract

Mining has been a key driver of Australia's economic development for more than two centuries. Approximately AUD 18.4 billion in mining products is exported every month, representing more than half (58%) of Australia's monthly export revenue (Australian Bureau of Statistics 2022). New mines to support the energy transition to a cleaner future will open, and operating mines with depleted resources will close. CSIRO anticipates that about 240 currently operating Australian mines will be entering the closure phase by 2040 (CSIRO 2023). Conservative estimates of expenditure on mine closure and remediation activities at these mines is up to AUD 8 billion annually (CSIRO 2023).

The mining industry is facing increasing community expectation and government regulation to close and rehabilitate mines in a manner that optimises social and environmental outcomes. This paper describes an innovative approach to mine closure planning that is being show-cased at the Energy Resources of Australia (ERA) former Ranger Uranium Mine, which is located within, but separate from, the dual World Heritage listed Kakadu National Park.

The approach uses bow-tie diagrams to provide, on a single page, a clear and transparent way of showing progress towards achieving environmental requirements and closure criteria. Each bow-tie diagram shows threats, preventative controls, corrective actions and residual risks. The predicted effectiveness of each control and corrective action is rated objectively.

This approach narrows the focus and attention of research and onsite activities for both the mining company and the regulator, thereby avoiding potential scope creep and reducing costs.

Keywords: *Ranger uranium mine, innovative mine closure plan*

1 Introduction

Mining has been, and continues to be, a key driver of Australia's culture and economic development. Some 65,000 years ago Aboriginal people started mining via the fossicking for stones suitable for tools and the collection of ochre that was used to make pigments for paint. European settlement established coal mining and export in 1791, with the first shipment to India (Brunel 2022). Lead was the first metal to be mined (1841), followed by copper in 1842 (Brunel 2022). Larger scale mining followed in the 1850s with the discovery of gold. At that time Australia was producing almost 40% of the world's gold (Brunel 2022).

Several publications quote the number of active and abandoned mine sites in Australia. Werner et al. (2020) interrogated multiple databases and validated entries across state and commonwealth departments. At the time of their publication (August 2020), there were 10,526 active mines and 84,794 inactive mines in Australia ('mines' included hard rock mines and quarries, numbers of each were not consistently recorded). Of the 84,794 inactive mines, 3,081 (or 3.6%) had been fully rehabilitated (which was defined as successfully completing remediation objectives with no further mining care and maintenance required by the authorities) (Werner et al. 2020). Having said that, Campbell et al. (2017) of the Australia Institute state that:

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'Mine closure, complete rehabilitation and relinquishment of the former mine site is almost unknown in Australia. There are no examples of major, modern open cut mines completing rehabilitation to the point where the site can be relinquished.' (Campbell et al. 2017)

Many of the inactive sites were abandoned before environmental compliance standards were applied to mine closure (Australian Senate 2017). Australian Senate (2017) define 'abandoned' as, 'arise when mining leases or titles no longer exist, and responsibility for rehabilitation cannot be allocated to any individual, company or organisation responsible for the original mining activities'. CSIRO (2023) point out that the liabilities and risks associated with mine relinquishment have only truly come to the forefront of government's awareness over the last 20 years. This heighted awareness has been accompanied by increasing expectations and regulatory requirements in the form of closure objectives and closure criteria. The ability of a mining company to demonstrate the achievement of closure objectives and criteria is essential to limit the residual risk to the government at the time when the mining company is seeking relinquishment of the mine tenure.

Most Australian jurisdictions require the submission of standalone site closure plans as part of the mining lease approval process (Australian Senate 2017). Guidance on the timing and content of such plans is provided in the Australian Government mine rehabilitation handbook (Grant et al. 2016) and the good practice guidance documents issued by the International Council on Mining and Metals (ICMM 2019) Section 3.3 of the mine rehabilitation handbook also cites multiple publications for use in various states and specifically for uranium mines (e.g. WA EPA 2015; DEHP 2014; DTIRIS 2013; ARPANSA 2005).

Common to many of these guidance documents is the requirement to meet three key closure objectives:

- the long-term stability of the landform
- the prevention of pollution of the surrounding environment
- the ability to sustain an agreed post-mining land use.

Beyond these high level objectives, more site-specific closure criteria are developed in accordance with the material environmental and social risks relevant to the mine site itself, the agreed post-mining land use, and the sensitivity of the surrounding environment. In most cases these closure criteria are drafted and negotiated during the planning and operational phases of a mine. However, it is in the performance tracking (i.e. monitoring results) and demonstration of achievement of these criteria during the closure phase and nearing relinquishment where subjectivity and debate may occur. This is particularly relevant where some, or many, closure criteria cannot be demonstrated by monitoring data until after relinquishment is being sought. For example, solute transport from an open pit may occur over decades and therefore demonstration against the closure criteria would be based on model predictions rather than monitoring data. As another example, ecosystem criteria may require the return of fauna that are reliant on tree hollows, but such hollows typically form when the trees are about 100 years old. Therefore predicting the trajectory of a functioning ecosystem and monitoring against that trajectory would be more relevant for relinquishment timing than counting the number of tree hollows.

Establishing an agreed process to reduce and manage this subjectivity is important to achieve mine closure, particularly in light of the vast number of abandoned mines under government management and the strong driver for government to ensure that they (or the next landowner in the case of private lands) are not inheriting any further ongoing and costly liabilities.

This paper describes an innovative approach to mine closure planning that is being show-cased at the Energy Resources of Australia (ERA) former Ranger Uranium Mine, which is located within, but separate from, the dual World Heritage listed Kakadu National Park in the Northern Territory. ERA produced uranium oxide for the global nuclear energy market for more than 40 years. The Ranger orebody, located on Mirarr country in the Alligator Rivers Region of the Northern Territory, was first discovered in 1969. Mining started from Pit 1 in 1980, and ore processing soon followed with the plant commissioned in July 1981. The first drum of uranium oxide was produced on 13 August 1981. Mining from Pit 1 finished in December 1994 and finished from the second pit (Pit 3) in November 2012. The last processing of stockpiled ore and the final drum of uranium oxide was produced on 8 January 2021, completing the mine's operational phase after producing a total of 132,000 tonnes of uranium oxide.

2 Methodology

With the mine now in the closure phase, ERA's focus is to create a positive legacy and achieve sustainable rehabilitation and closure of its former mine assets. The environmental closure objectives that ERA must now close the mine are set out in the Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (the Environmental Requirements [ERs] can be likened to the closure objectives noted prior and to avoid confusion for those not familiar with this terminology this paper refers to the ERs as closure objectives). For the Ranger mine, there are two primary closure objectives, from which 32 closure criteria have been developed. The closure objectives, among other requirements, require ERA to transfer all tailings from the tailings storage facility into the mined out pits and to avoid any detrimental environmental impact from any contaminants arising from the tailings for at least 10,000 years.

The first Ranger Mine Closure Plan (MCP) was submitted to the Commonwealth Minister for Resources and Northern Australia, and the Northern Territory Minister for Primary Industry and Resources, in May 2018 (ERA 2018). The MCP is ERA's primary mechanism to describe the closure activities and rehabilitation. The MCP seeks to consolidate the relevant information from the last 40 years and demonstrate how the current planned closure and rehabilitation activities will achieve the closure objectives. To ensure its currency, and to incorporate lessons learnt from ongoing engineering, scientific and monitoring studies, the MCP is updated and submitted for regulatory approval annually.

From 2018 to 2022 the Ranger MCP was developed in accordance with the Western Australian Guidelines for preparing mine closure plans (WA EPA 2015). Whilst these plans contained closure objectives and closure criteria, and collated the key findings of more than 40 years of research projects and onsite monitoring data, the plans did not specifically outline the progress towards the achievement of closure objectives or closure criteria. Numerous studies were being progressed across multiple themes (e.g. landform, water and sediment, soils, ecosystems, radiation, cultural) but as scientific questions and knowledge gaps were answered, more still arose. The focus of attention was on good science and chasing all unanswered threads. This widened the scope of data collection and research studies, which in turn increased the expectations that each closure criteria, irrespective of the residual risk, would be supported by a plethora of robust scientific studies.

Following eight months of consultation with regulators, a revised structure for the 2023 Ranger MCP was supported, and the plan was published three months later (ERA 2023). The new structure more readily enabled the MCP to clearly and transparently describe the progress towards achieving each closure criteria, and the activities that are yet to be completed in order to reduce residual risk. The primary chapters of the document are based on the main themes (i.e. landform, water and sediment, soils, ecosystems, radiation, cultural) and discuss the following:

- Closure Criteria: whether the closure criteria have been approved by the Commonwealth Minister as part of a previous MCP or whether there is further work required.
- Relevant Studies/Knowledge Base: summarises the studies that have been completed or are being undertaken to demonstrate that the closure criteria can be achieved.
- Bow-tie diagrams: this MCP uses bow-tie diagrams to provide on a single page clear and transparent way of showing progress towards achieving the closure criteria. Depending on the theme, there may be multiple bow-ties, representing the relevant aspects being measured for that theme. For example, there are 17 bow-ties in total that address the two primary closure objectives and 34 closure criteria.
- Preventative Controls: how well do we understand and can demonstrate the effectiveness of the controls that will be put in place between now and the creation of the final landform, or shortly thereafter, to ensure that closure criteria can be achieved or are on the desired trajectory to being achieved.

- Monitoring Program: the monitoring program that will be implemented to confirm the accuracy of predictions towards the achievement of closure criteria, or to detect an undesirable outcome and thus a deviated trajectory.
- Corrective Actions: how well we understand and can demonstrate the effectiveness of corrective actions that if implemented would recover a deviated trajectory to a desired trajectory within an acceptable time frame, and would avoid unacceptable health, environmental and cultural impacts.
- Trigger, Action, Response Plan: this is a tool that brings together much of the information from the above topics. It provides clear direction on who does what and when if the early warning triggers of the monitoring program detect movement away from the desired trajectory.
- Future work: each of the above sections may identify areas in which future work is required. This work may be a study that is required to fill a material knowledge gap or it may be further engineering to strengthen the effectiveness of a preventative control or corrective action.

The use of the bow-tie diagram is instrumental in targeting the focus and attention of research and onsite activities for both the mining company and the regulator, thereby avoiding potential scope creep or the introduction of unnecessary engineered structures; thus reducing closure costs. This approach is not new, it is thought to have originated in the late 1970s in Imperial Chemical Industries, however it was not until the early 1990s that Shell became the first company to incorporate bow-ties into its operations for process engineering safety audits (Anderson et al*.* 2016). Following Shell, the bow-tie method started to be used widely throughout the oil and gas industry, as bow-ties became known as a powerful visual tool to aid risk management (Anderson et al*.* 2016).

3 Data

Figure 1 provides an example of the bow-tie as applied to one of the closure criteria for the Ranger project. In this example the criteria relates to the need for the rehabilitated landform to support a particular vegetation composition, abundance and community structure (in Ranger's case a community similar to those in adjacent areas of Kakadu National Park). Therefore, the centre of the bow-tie is worded in a format that reflects the risk of that criteria not being achieved. The components of the bow-tie and the order in which they were developed are as follows:

1. Green boxes on the left hand side: these are a list of threats that may hinder the achievement of meeting the closure criteria. The threats were identified by:
   a. Reviewing the closure criteria that has been developed for each closure objective, with the rationale that by not achieving closure criteria the related objective would not be achieved, and therefore that is a plausible threat.
   b. Reviewing of the risks identified during previous risk assessments and scientific studies to determine if other plausible threats should be included.
2. Identify the preventative controls: these are identified by reviewing the already executed and planned closure activities that are relevant to managing this particular criteria. These controls are typically design elements of the project that when successfully executed will mitigate potential impacts and facilitate the achievement of the relevant criteria. In many cases these controls can be implemented during the operational phase and prior to the creation of the final landform, hence the term 'preventative' controls. All preventative controls have been assigned a unique identifier and colour-coded as either an 'Active' control (either currently active or planned – coloured light green) or 'Knowledge-based or administrative controls' (coloured dark green). This distinction is important when categorising the effectiveness of the control, which was completed by reference to the descriptions provided in Table 1.

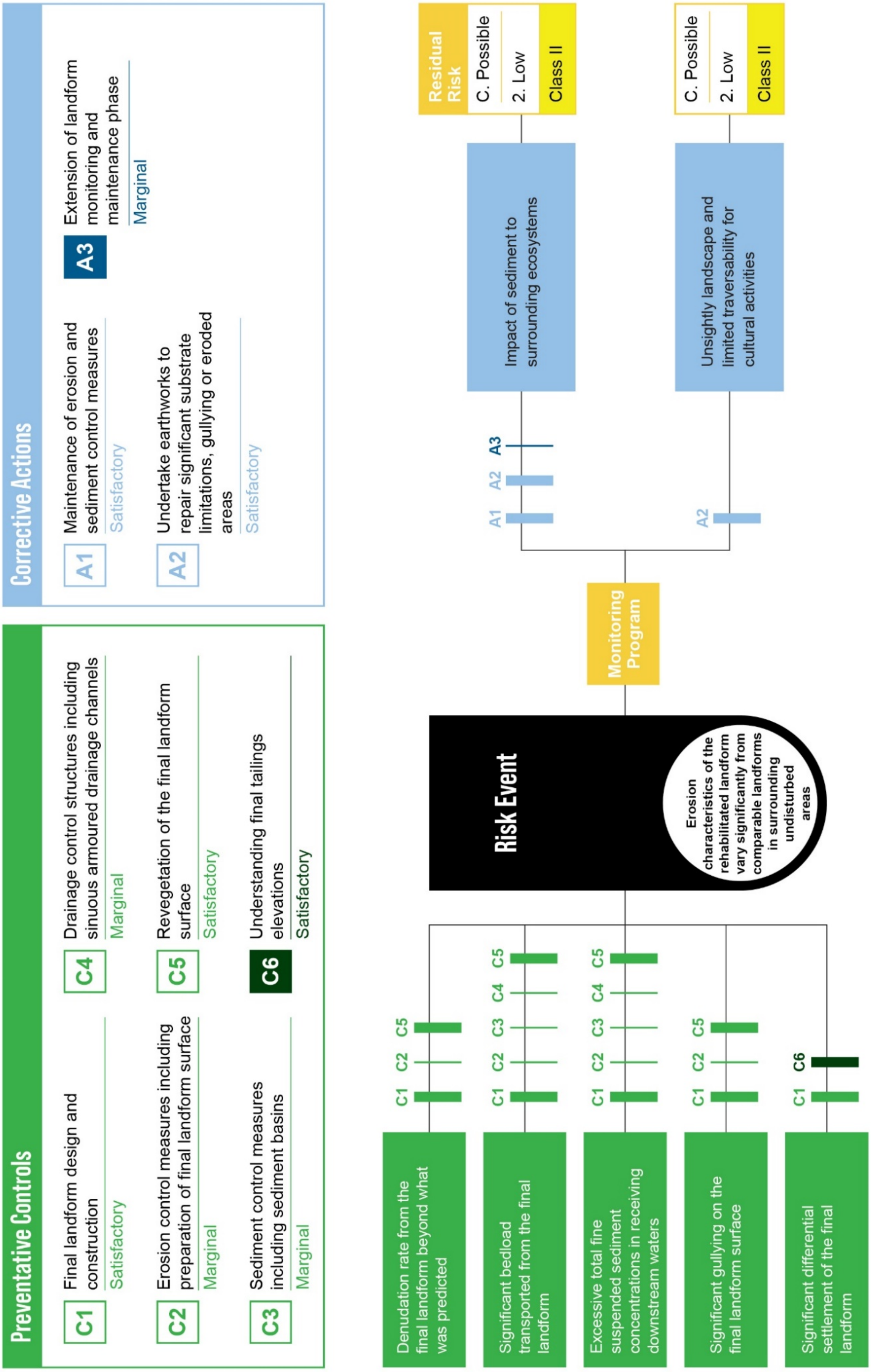

Figure 1 Example Bow-tie

Table 1 Descriptors used to assess effectiveness of preventative controls and corrective actions

Description of Status	Effectiveness Rating
Design activity: Proven technology, already installed/constructed and monitoring has demonstrated effectiveness of the design/activity. Clearly defined and well communicated to execution teams, appropriate quality assurance program during construction/rehabilitation, supported by a suitable and feasible monitoring plan **Knowledge-based/administrative:** Not applicable for ‘strong’ preventative control or corrective action **Timing:** ERA resources available and control/corrective action will be successful within 10 years of implementation	Strong
Design activity: Proven technology, monitoring has demonstrated effectiveness of the design/activity. Clearly defined and well communicated to execution teams, appropriate quality assurance program during construction/rehabilitation, supported by a suitable and feasible monitoring plan **Knowledge-based/administrative:** Supported by studies and/or knowledge base with accepted/approved methods and findings, aware of uncertainties and deemed acceptable (i.e. not to have a material effect) Timing: ERA resources available and control/corrective action will be successful within 15 years of implementation	Satisfactory
Design activity: Preliminary design, not yet proven at Ranger, monitoring has demonstrated partial effectiveness of the design/activity. Clearly defined and well communicated to execution teams, appropriate quality assurance program during construction/rehabilitation, supported by a suitable and feasible monitoring plan **Knowledge-based/administrative:** Supported by studies and/or knowledge base with methods not yet accepted/approved, many uncertainties and insufficient information to deem whether uncertainties are material **Timing:** ERA resources available and control/corrective action will be successful within 25 years of implementation	Marginal
Design activity: Concept design, not yet proven at Ranger, monitoring has not yet demonstrated effectiveness of the design/activity. Not yet defined and well communicated to execution teams, ill-defined or absent quality assurance program during construction/rehabilitation, not yet supported by a suitable or feasible monitoring plan **Knowledge-based/administrative**: Speculation, no supporting data, methods not yet accepted/approved, many uncertainties and insufficient information to deem whether uncertainties are material **Timing:** No certainty of ERA resources, uncertainty as to whether control/corrective would be successful at any point in the future	Weak

3. Develop undesirable outcomes that may occur if a deviated trajectory is detected by the monitoring program (in this example there is just a single undesirable outcome).
4. Establish corrective actions that would be implemented to recover the deviated trajectory back to the desired trajectory, and then assess the effectiveness of those actions using the descriptions provided in Table 1. As with preventative controls, all corrective actions are assigned a unique identifier and colour-coded as either ‘Active’ (coloured light blue on the bow-tie diagram) or ‘Knowledge-based or administrative’ (coloured dark blue).
5. Quantify the consequence and likelihood, and thus residual risk rating, for each of the undesirable outcomes using risk look-up tables (these tables are standard risk assessment tables that are often tailored for the particular mine site or mining company).

4 Results

The restructuring of the Ranger MCP and the development of the 17 bow-ties took approximately 11 months. The benefit of this exercise is a clear picture to ERA and the site’s regulators on the key metrics proposed to identify residual risk and the current progress towards reducing that risk. Future work can now focus on those aspects with high (Class IV) and moderate (Class III) residual risks. More importantly, that work can be directed towards strengthening the effectiveness of ‘weak’ and ‘marginal’ preventative controls and corrective actions, rather than spending time and money investigating and executing additional activities onsite that may improve an aspect of the closure project that already has a negligible (Class I) residual risk or ‘strong’ preventative controls.

During the senate inquiry (Australian Senate, 2017), the Minerals Council of Australia noted that a mine life can span several decades or more, over which time community expectations and environmental standards may change. It argued that certainty in the rehabilitation standard for each mine site is required in order for industry to plan its operations properly, and that changes to rehabilitation standards should not operate retrospectively:

> *‘It is appropriate to expect modern mining operations to meet contemporary criteria; however it is inappropriate to apply these criteria retrospectively to sites that have been previously approved and are working in good faith to meet the legal obligations associated with those approvals.’* (Minerals Council of Australia, 2017)

The use of the bow-tie risk process in mine closure planning seeks to reduce the subjectivity in assessing the achievement of closure criteria that may otherwise arise when the mining company is nearing relinquishment. As per the request from the Minerals Council, it provides a process to work with regulators to promote certainty in the closure standards.

5 Conclusion

There are many components and complexities that influence the achievement of effective mine closure. This paper does not purport to answer all of these. Rather, it introduces to mine closure planning a powerful tool to aid risk management. The approach of using bow-ties narrows the focus and attention of research and onsite activities for both the mining company and the regulator, thereby avoiding potential scope creep and reducing closure costs.

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