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Environmental impacts of uranium mining in Australia

History, progress and current practice

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POLICY PAPER

Minerals Council of Australia

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The Minerals Council of Australia is the peak national body representing Australia's exploration, mining and minerals processing industry, nationally and internationally, in its contribution to sustainable economic, and social development.

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Executive summary

The now decades-old anti-nuclear movement has sought and continues to seek the opportunity to disrupt the operations of the nuclear fuel cycle. A consistent pattern and approach has involved actions that aim to raise the cost of doing business in the nuclear fuel cycle.

It is reasonable to consider whether uranium mining presents a uniquely high level of environmental hazard or concern, or whether it simply receives a uniquely high level of attention and activism from anti-nuclear groups.

This review of the literature relating to the historical and current practices and environmental impacts of uranium mining in Australia suggests the latter is certainly true: the potential for environmental impacts is influenced by the quality of planning and regulation, not the mineral that is being sought.

This review also identifies that at the global scale, serious environmental impacts occur via unregulated or poorly regulated mining practices, including and not limited to several commodities of vital importance to non-nuclear, renewable energy systems, including rare earths and lithium. The exceptional focus placed on proposals for modern uranium mining in the relatively well-regulated Australian setting arguably squanders resources, media attention and supporter goodwill that would be better directed addressing the world's genuine mining trouble-spots.

In the past, uranium mining in Australia has certainly delivered some poor environmental impacts. The Rum Jungle mine is a stand-out example of a poorly regulated mining operation leading to legacy environmental impacts that are difficult and costly to remediate. This is particularly due to acid-rock drainage processes, not unique to uranium mining, leaching other (non-uranium) metals into the local environment.

However, the literature indicates a clear trajectory of progress through the management of the Nabarlek and Mary Kathleen mines, with mostly satisfactory environmental outcomes. In the case of the Ranger uranium mine, the level of study, reporting and disclosure of environmental performance from the earliest stages of the mine to the present day render the industry almost unrecognisable from its early days. The Olympic Dam operation similarly shows clear evidence of the transition to the modern mining era. The in-situ recovery processes applied to the uranium mines in the Curnamona Province of South Australia are arguably delivering world-leading environmental outcomes *across commodities*, and are applied in pursuit of uranium.

In contrast, the rare earth mining boom in some developing countries such as China and the lithium mining boom in South America are reminiscent of the early, under-regulated era of mining in Australia. In these settings, the literature suggests illegal and unregulated mining activity may be leading to serious environmental impacts and possible harmful legacies. Scientific understanding in Australia concerning the environmental impacts of uranium mining appears to be much greater than it is for other minerals in these jurisdictions, as does the level of regulatory oversight.

The finding of this review is clear: the nature of mining practice and regulation are the key determinants of environmental outcomes. The mineral in question plays a far lesser role if any. All mining practices demand proper scrutiny, regulation and the evolution and adoption of leading practices to ensure adequate planning for environmental protection and clear forward liabilities for the management of the site through operations, progressive rehabilitation, closure, and monitoring phases. Regulators should apply scrutiny dispassionately and even-handedly. Similarly, activist organisations should seek, on the basis of evidence, to focus on the areas of most serious environmental concern to bring about lasting improvements and better outcomes, regardless of where these impacts occur in the world and regardless of the end use of the commodity being pursued.

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1 Introduction

It is acknowledged that modern society could not function without the products of the extractive mining industries and that these processes invariably involve environmental impacts.[1]

Responsible mining practices, therefore, seek to identify potential impacts and to prevent, avoid, mitigate and manage them across the life of the mine and through to closure.

Mining for any commodity, thus, demands careful management. A higher-than-average level of attention and scrutiny in Australia appears to fall on the past, present and potential future operations for the pursuit of the mineral uranium. Literature suggests the origins of this attention stem from the apparent blending and evolution of a global movement of weapons and peace-related concerns, including those tied to the testing of weapons in Australia and the Pacific, into mainstream environmentalist objections to the mining and subsequent use of uranium as an electricity generating fuel in civilian power-generating infrastructure.[2]

The wholesale rejection of uranium as a clean fuel by the environmental movement has largely been maintained, despite the current deployment of nuclear energy likely displacing between 1 billion and 2.5 billion tons of carbon dioxide equivalent from global energy systems every year, and the notable success of France in using the technology to almost entirely displace a fossil-fuel based electricity generation sector. There is now a notable and growing movement of pro-nuclear environmentalism stemming largely from concerns relating to energy and climate change.[3]

Between a vocal movement opposed to uranium mining with origins in non-proliferation sentiment, and an increasingly vocal movement supporting the end-use of the mineral as a clean fuel, informed and evidence-based discussion about the actual environmental impacts of uranium mining is easily drowned out. This literature review examines the question of whether uranium mining practices pose environmental impacts or environmental management challenges that can be reasonably regarded as exceptional among extractive industries.

The review examines literature relating to past and presently operating Australian uranium mines. To place those issues in suitable context, the review begins by considering literature that examines environmental challenges common to mining across commodities.

2 Tailings management: a comparison of approaches

In any extractive process, some environmental impacts can be expected, though their extent and degree can cover a wide range across mining processes.

Impacts may include clearing of land of vegetation, disturbance of land (such as the removal of overburden and then accessing the mineral resource itself), consumption of water and the possibility of unregulated/ accidental discharge of potentially hazardous chemicals and processes.

A review of the literature finds tailings management, common to most mining, provides a useful indicator to compare environmental performance and regulation. It is, therefore, pertinent to firstly consider general practices and concerns relating to the management of tailings for any minerals, and consider whether a case for exceptional concern is apparent in the management of tailings in uranium mining.

'Tailings' is a general term that refers to mixtures of crushed rock and processing fluids from mills, washeries or concentrators that remain after the extraction of 'economic metals, minerals, mineral fuels or coal from the mine resource'.[4] Some extractive mining operations, such as some iron ore mining in the Pilbara region for example, proceed without production of tailings, producing instead simple crushed, screened and blended ore products.

Large volumes of tailings waste is commonplace with production of 5-7 billion tonnes of tailings worldwide every year.[5] Failure in tailings management processes can result in catastrophic consequences.[6]

Acid rock drainage (ARD) presents perhaps the most serious risk for long-term environmental impact that can arise from mine tailings and therefore requires appropriate planning and management. ARD refers to the oxidation of newly exposed minerals and rock, particularly common sulphide bearing minerals like pyrite, which react with water to create sulphuric acid.[7] The acid, in turn, can leach residual metals from the tailings. These metals can become serious off-site pollutants in waterways and enter the biological food chain unless appropriately managed.[8]

Two points pertinent to uranium mining are readily apparent. Firstly, the production of tailings is commonplace and not limited to, or exceptional in, the case of uranium mining. Secondly, ARD and its consequences similarly are unrelated to uranium *per se* and can occur in the extraction of many mineral deposits in the absence of suitable management. For example, a small and little-known mine in South Australia's Mount Lofty Ranges, close to rural communities, was identified in assessment as having serious potential for ARD.[9]

The use of retention ponds or dams for the management of tailings is the main management method for larger mines in developed countries.[10] More robust tailings dam designs and practices have evolved with experience including more careful consideration of acceptable dam design accounting for the potential for extreme weather events and of seismic conditions.[11] Other active techniques include better management of water balance, active dewatering of tailings, and other innovative methods.

A breadth of governmental, industry and academic literature affirms widespread efforts to extend the discussion of tailings management into pro-active controls from the earlier stages of the mining design and practice.[12]

Authorised practices vary from country to country. For example, 16 mining operations (0.6 percent of mines worldwide) dispose of tailings directly to the ocean (submarine tailings disposal) or river (riverine tailings disposal).[13] The latter process, in particular, can result in serious environmental impacts and is practised in four mines based in Asia.[14] No mines in Australia (and therefore no uranium mines in Australia) use tailings disposal into river or shallow submarine approaches.

A general review of tailings management affirms that i) appropriate management of tailings is critical ii) practice is generally improving with continual innovation and appropriate regulatory oversight and improved standards iii) serious environmental and safety consequences can occur if tailings storage facilities fail. These concepts appear to be generic across many minerals and are neither constrained to nor exceptional in the case of uranium mining.

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3 Human health and radiation hazard management

The environmental impacts of uranium extraction include both impacts present in any mineral extraction and effects unique to the chemistry and radioactivity of uranium and its daughter products.[15]

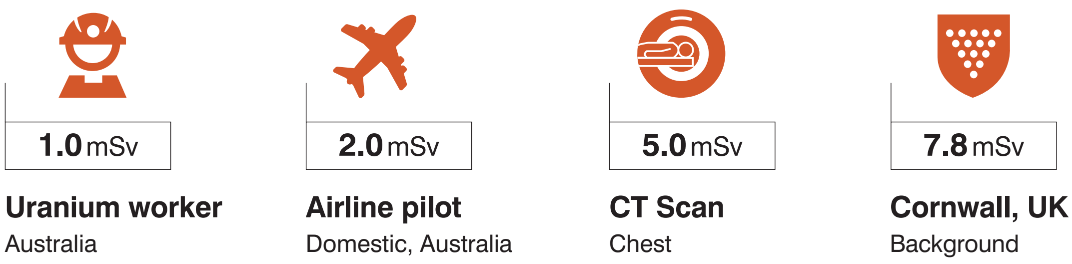
While the radioactive products of concern occur naturally, the mining and milling process can serve to make them more available to human exposure and distribution in the environment.[16] This concern exists in the context that a baseline level of radiation exposure is normal, unavoidable and variable based on factors including geographic location, availability and use of nuclear medicine technology and occupation.

Elevated exposure to some types of radiation is known to have the potential for serious human health consequences. This is well-documented from many sources including the earlier years of the uranium mining industry, particularly in relation to the impacts of radon ingestion and a synergistic effect with cigarette smoking.[17]

Nonetheless, uranium mining can be and is undertaken without elevated levels of radioactivity that may cause negative health impacts for either workers or the environment. Australia is a good example, with stringent safety protocols now in place. The Australian National Radiation Dose Register confirms that average additional worker dose in the Australian uranium industry is ~one-half of the additional dose of professional airline pilots and ~1/8th the normal background dose in Cornwall, UK.[18] In India, examination of a mine found return to background levels of radioactivity only a short distance from the embankment of the tailings facility.[19] In Spain, radon concentrations have been -found to be two-to-ten times lower in operating uranium mines than in popular tourist visitation caves.[20]

It is evident that uranium mining can be conducted with proper management of this hazard, well within the levels of risk that are routinely accepted in other industries and non-work related activities.

Present day annual exposures to ionising radiation



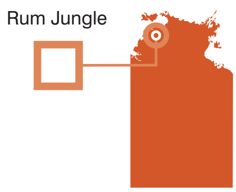
Source: Australian Radiation Protection and Nuclear Safety Agency, *ANRDR in Review 2016*

4 Management of environmental impacts

In Australia, a clear progression in environmental outcomes and practices is evident from a review of literature pertaining to four open cut uranium mines: Rum Jungle, Mary Kathleen, Nabarlek and Ranger and then the larger and more complex underground operation of Olympic Dam.

A further development in practice is then observed in the use of in-situ recovery mining at mines in the Curnamona province in South Australia.

Case studies of uranium mining in Australia



Rum Jungle

Northern Territory

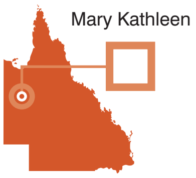
The Rum Jungle deposit was mined between 1954 and 1964 with all operations ceasing in 1971. The practices that characterised the Rum Jungle mine are representative of the ineffective early regulation, both within Australia and other nations, that was typical in mining (and other industries) at the time, with little forward planning and insufficient regard (by today's standards) for environmental impacts.[21]

A low priority was placed on environmental protection, inadequate pollution controls were in place and the quality of containment structures was similarly poor. These shortcomings led to serious environmental impacts on the mine site and the east branch of the Finnis River. ARD of metals from the waste rock was the main contributor of these impacts, including pollution from copper, manganese, zinc and sulphate.

Uranium and daughter products themselves have not been the contaminants of greatest impact.[22]

In 1983 a rehabilitation project was undertaken to improve the site, reduce pollution, cover waste rock, relocate tails and reduce the water flow.[23] These actions provided substantial improvements to the site. However, subsequent reviews have shown deterioration of the works. This, combined with evolving standards and expectations, led to new studies for longer term rehabilitation.[24] A new project agreement is in the process of being finalised.

Overall, the Rum Jungle mine represents a poor environmental outcome. It combines inappropriate standards of mining from an era that is broadly regarded as prior to effective worker and environmental controls, with unclear forward liabilities for the site. It is also an example of the challenges that ensue if polluting processes are permitted to get out of control. Ironically, for a flagship example of poor uranium mining, it is not uranium but other metals from the waste rock that present the most serious ongoing pollution concerns.

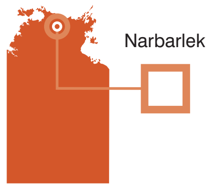


Mary Kathleen

Queensland

The Mary Kathleen mine was subject to rehabilitation during the 1980s following uranium extraction from 1956 to 1963 and from 1976 to 1982.[25] The rehabilitation was completed in 1982 to a level that would be regarded as basic compared to today's standards.[26]

Review of the site performance indicates that the rehabilitation cover has contained the waste adequately, with some potential seepage at rates greater than previously expected and some infestation of noxious weed in the rehabilitated areas.[27] Mary Kathleen represents a partial success and a clear improvement in outcomes compared to Rum Jungle, with better rehabilitation performance over a period of decades.



Nabarlek

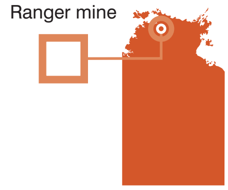
Northern Territory

The Nabarlek mine was a high grade, small size deposit that was mined intensively over a period of 143 days in one season, with the ore stockpiled for subsequent processing.[28] Mining was completed in 1979, and the milling processes continued until 1988.[29]

The mine pit was re-used as a tailings repository, and the residual mine void was capped. Early modelled estimates suggested the cap would effectively contain the tailings for tens of thousands of years.[30]

A subsequent review in 2005 found the area containing the mine tailings to be extremely stable.[31] Small areas of accelerated sediment loss were flagged for potential further rehabilitation. However, overall rates of erosion were close to the original 1995 estimates.[32] The process and outcomes at Nabarlek are indicative of further improvement in planning, delivering and monitoring of tailings management and rehabilitation. The 2005 review stated:

> Rehabilitation work was completed at the end of 1995. After the onset of the wet season, vegetation cover was found to be good, with no ponding and little erosion. Monitoring and research will continue, and Nabarlek represents the first rehabilitation of a uranium mine in Australia according to current principles and practice.[33]



Ranger mine

Northern Territory

The most modern open-cut uranium mine considered in this review, the Ranger uranium mine is unique for the intensity of monitoring, regulation and reporting of environmental impacts, including by the specially created Office of the Supervising Scientist of the Commonwealth Government. The Ranger mine is separated from but surrounded by the Kakadu National Park, the park itself having been established in response to a recommendation from the Fox review considering uranium mining in the region. Being located in an environmentally sensitive area, it is pertinent to consider the impact of mine activities compared to other risk factors in protecting these ecosystems. Bayliss et al find non-mining risks to be several orders of magnitude greater, highlighting the impact of invasive species and climate change as two risk factors of far greater import to the protection of the natural environment than the potential impact of the mine activities.[34]

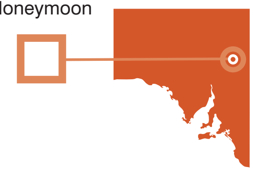
The greater focus on environmental protection in the modern era is evident in the availability of scientific literature regarding this mine from the early stages of development and operations. Literature from early in the mine life demonstrates active research and investigations to understand the site's environmental attributes and risks.[35] Active monitoring of water releases has been undertaken from early stages demonstrating effective control of radionuclide levels and no increase in concentration from sediments.[36] The use of turbidity measurements as a surrogate for sediment concentration was under criticism in 1997-98.[37] Well before mining completion, early-stage modelling was undertaken to test the efficacy of a tailings containment design in meeting the required standard.[38] The potential mobility of radionuclides and managanese from spraying of waste water has been assessed as well as ongoing research into the potential for uranium and thorium uptake in bush food.[39] Hart et al summarise both the broader and increased focus and attention on social and environmental responsibility in the mining industry, particularly since the turn of the century, and also specifically the continually evolving requirements on the operations of Ranger mine 'as conditions have changed and new knowledge acquired'.[40]

Many aspects of environmental and radiological management at the site are under more recent and continuing study, evaluation, and publication.[41] This includes, for example, participatory approaches to surface water monitoring and management that have resolved some historical concern between mine operators and the local indigenous Mirrar people and many other areas of study. One study of radium accumulation in downstream freshwater mussels indicated no significant change in the 25 years of mine operation, demonstrating the value in long-term monitoring to permit robust assessment of environmental impacts over time. Radon exhalation has been examined for different climatic conditions across the year and the Office of the Supervising Scientist has reported annually from 1997 to 2014-15.[42]

Incidents of containment failure have been recorded at the Ranger mine. One more serious case was an undetected slow leak of tailing water resulting in a loss of material from the site in 1999. The cause was recorded as deficiencies in monitoring and maintenance, exacerbated by a lack of timely reporting. Investigations following the reporting of the leak indicated no discernable impact on water quality either downstream at the point of waterway entry or at a billabong much closer to the site. Estimated potential exposure to local people was negligible (approximately 1,000 times below limits).[43] The failure of a leach tank in 2013 was fully contained within the operating area and was extensively investigated. The Office of the Supervising Scientist concluded 'that the leach tank failure has not resulted in any adverse impacts to human health or the surrounding environment, including Kakadu National Park'.[44]

Tailings management at Ranger is based on the 'in-pit' process, meaning the emplacement of tailings back in the mine void. A review of these processes and statutory requirements found that the they are 'among the most stringent in the world – and should clearly be considered world's best practice' and furthermore that the practice should be considered world's best 'not only for radioactive uranium tailings in the wet-dry tropics but also mine tailings in general'.[45]

> The baseline environmental impacts of ISR mining, be it of uranium or other minerals, are expected to be a priori lesser than open cut or underground mining. Again, the defining element appears to be mining practices, not minerals.

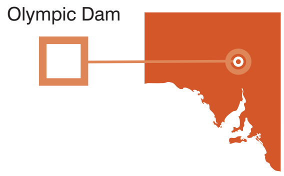


Beverley/Honeymoon mines

South Australia

The operations of the Beverley/Honeymoon uranium mines diverges from open cut mining to apply the use of in-situ recovery (or ISR) mining techniques. ISR mining allows the extraction of the mineral ore without surface disturbance beyond the sinking of small-diameter wells for the injection of reagents that facilitate mineral mobilisation and the extraction of elements of economic interest. The extracted solution is then transferred to a plant to recover the mineral. Once the ore-bearing solution is stripped of the desired mineral(s), the remaining fluid is reinjected to the ore body where it is recycled through the process described above. This technique is used for mining several minerals in suitable conditions (e.g. copper) and has been successfully applied to uranium mining in Australia. The technique requires no open pits, rock dumps, tailings storage (be it a tailings dam or other method) and no large-scale water consumption as it is continuously recycled through the extraction/injection well/plant system. The overall environmental impact of such mining operations can be expected to be greatly reduced compared to the baseline impacts from an open-cut operation; provided projects are adequately planned, operated and closed.[46]

An area of concern for environmental impact in ISR mining is the potential spread of the re-injected fluids into other groundwater systems/aquifers not used in the mining process. A review of conditions and performance at the Beverley uranium mine highlights that i) under nearly any circumstances the active management of this risk is preferable to the challenges of surface disposal, ii) movement of reinjected fluids is slow, and iii) natural attenuation of the groundwater used in ISR mining is expected to return to normal conditions within a timescale of years to decades.[47] This process of attenuation may now be evident in monitoring outcomes from some remediated ISR mines. However, the availability of data in published literature to date is minimal, and thus the publication of further field data is required to publically affirm this process.[48] Nonetheless, the baseline environmental impacts of ISR mining, be it of uranium or other minerals, are expected to be *a priori* lesser than open cut or underground mining. Again, the defining element appears to be mining practices, not minerals.



Olympic Dam

South Australia

The Olympic Dam mine is one of the largest mines in Australia and the second largest producing uranium mine in the world. It presents a considerably more complex mining operation than other Australian uranium mines, due both to the size and also the poly-metallic nature of the deposit and operation. While the primary material is copper, Olympic Dam is also producing economically viable streams of gold and silver and of course uranium. Due to the scale of the operations and the multiple metals processed, the simple environmental footprint of the mine is much larger than other uranium operations in Australia. The underground mining processes in an arid environment results in different challenges relating to water consumption and management than, for example, the open cut mining in a tropical environment typified by Ranger or the in-situ recovery operations in arid conditions undertaken in the Curnamona Province of South Australia.

Olympic Dam officially opened in 1988. This milestone can be considered the beginning of the modern era of Australian mining, with an Environmental Impact Assessment of the original operation.[49] Similarly to the Ranger uranium mine, there is evidence of early scientific investigations to gauge the environmental conditions in relation to radioactive material, baseline conditions of key indicator species for radiation and use of other indicator species for general environmental health. [50] Ongoing efforts in the use of bioindicators for assessing environmental health were summarised in 2005.[51] Recent approvals processes have placed conditions relating to early design, assessment and modelling of eventual tailing storage facility closure processes. In all cases, and evidently in the case of a mine the size of Olympic Dam, environmental impacts have and will occur. However, the distinctions in practice, information, and evidence between Olympic Dam (as well as Ranger and the Curnamona mines) and cases like Rum Jungle, Mary Kathleen and Nabarlek are evident.

The Olympic Dam mine maintains five tailings storage facilities. None are yet at the closure and rehabilitation stages, though three have met original design heights. Spills relating to uranium are publicly reported, with 38 reported incidents from 2003. Reported incidents range from some hundreds of cubic metres of tailings material from pipe failures to single grams of ammonium diuranate escaping process areas.[52] In none of these cases was serious or material environmental harm or exposure to the workforce or public reported.

The tailings themselves represent a form of low-level radioactive waste. Environmental and human exposure to radioactive tailings and disturbance from uranium mining is a matter sometimes exploited in arguments relating to the environmental and health hazards of the mine.[53] Conversely, the same researcher has argued for the uranium product to be left behind in the ore necessarily increasing the radioactivity of the tailings.[54] It is apparent that consistent, evidence-based approaches relating to environmental and human health impacts are important in contentious areas such as, and not limited to, uranium mining.

Given the size of the Olympic Dam resource, the future of this mine is likely to be long, potentially through to the end of the century, with potential future changes in operations. Other uranium mining operations in Australia will likely be commissioned, completed, and rehabilitated in this time. The Olympic Dam mine further demonstrates the heterogeneous nature of uranium mining in Australia, occurring as it does in a range of environments, conditions, sizes and mining techniques and, in this case, with the production of other valuable metals.

5 Lithium and rare earth mining: comparative examples

For the purposes of contextualising environmental impacts and the level of activist attention, mining for materials of importance to the burgeoning renewables energy sector has been selected.

The mining of rare earth elements and lithium in major producing countries (outside Australia) receive relatively little activist scrutiny and therefore provide a useful benchmark to compare environmental performance.

Rare earth elements mining in China

China dominates global rare earth production. In 2011, **over 95 per cent** of global rare earth supply originated from China.

Demand for rare earth metals is growing rapidly because of their usefulness in high-tech products including electric vehicle motors, LEDs, mobile phones and renewable generations technologies (e.g. wind turbines and solar panels).[55] Their end-use may also contribute to the establishment of lower-carbon-emitting energy systems in the global economy. However some of the impacts of the investment surge in mining between 2005 and 2011 in countries outside Australia are reminiscent of the earlier era of uranium mining: relatively ungoverned, poorly studied or understood, and likely to be generating environmental impacts that will demand remedial management in future.

Currently, China has an uncontrolled illegal market segment that supplies 30 per cent of global rare earth demand.[56] The materials are mined with no license or royalties paid, and with no regard for environmental impact.[57] The environmental impacts include the release of heavy-metal contaminated waste water and leaching solution into the environment and soil erosion, air pollution, water pollution, biodiversity loss and human health impacts.[58] Every tonne of ore is estimated to result in the environmental release of 1,000 tonnes of wastewater containing heavy metals and leaching solution.[59] It has been estimated that the environmental remediation costs of this unregulated practice will **exceed** the market value of the mined products.[60]

Lithium mining in South America

A similar situation exists for lithium. Much of the world's known lithium resources are concentrated in the Andean regions of South America, (Bolivia, Chile and Argentina) with other large known resources in China, the United States and Australia.[61]

The mineral is commonly extracted from the pumped and evaporated brine of salt flats, which must be put through further chemical processes. The processes involve diversion of water in arid territories from other uses, including human requirements, and requires the use of potentially hazardous chemicals that are subject to risk of spills, leaching and emissions.[62] Concerns regarding labour standards have also been raised in the South American setting.[63]

Demand for lithium has grown quickly as a result of the demand for batteries in electronic devices including electric vehicles. Furthering the penetration of variable renewable energy sources is, at this time, strongly tied to expectations of lower cost and greater numbers of larger scale batteries.[64]

Lithium itself raises specific and serious environmental concerns requiring appropriate management and oversight. Lithium is toxic, highly reactive and flammable, complicating efforts for collection and recycling. Currently, most lithium is either dumped or incinerated. Thus demand for new lithium production is rising.[65]

Overall, relatively little is known about the environmental impacts of the production, use and disposal of the lithium-ion batteries.[66] This is reflected in the availability of many popular media articles identifying potential and actual environmental and community impacts from lithium, combined with a relative dearth of robust academic literature describing these risks and impacts and how they are being managed and mitigated.[67] Early studies indicate that a relatively small proportion of the environmental impact of, for example, electric vehicle batteries relate to lithium itself.[68] However, these impacts in sensitive areas are cause for growing concern.

International lithium and rare earth mining conclusions

It appears that the earliest stages of the lithium and rare earth mining boom outside Australia are akin to the earliest stages of uranium mining: operating in some cases with i) low visibility; ii) low standards; iii) a limited base of scientific knowledge to plan and mitigate environmental impact; and iv) little lifecycle environmental planning. The rapid growth in demand is likely to spur increased production. The risk of poor planning for environmental protection may therefore increase.

Nonetheless, lithium mining is positively endorsed by some renewable energy proponents due to the contribution to the battery industry, with seemingly little criticism or scrutiny of environmental impacts.[69] This is despite lithium developments in Australia having characteristics commonly highlighted by anti-nuclear organisations in combatting uranium mining: open cut mining in Australian wilderness areas, tailings production and chemical extraction processes. While such lithium or rare earth developments would be required to meet Australia's environmental regulations, this is the case for any mining development, such as that of uranium. A double-standard appears to be in play in terms of how some in the environmental movement engage with mining developments based not on the environmental risks, but on the end-product.

Moreover, regarding rare earth mining, Gavin states:

> The production of rare earth minerals present potential risks for the environment wherever it is carried out in the world. The key challenge facing the industry, therefore, is how to mitigate the severity of those risks by the use of best available environmental technologies combined with proper management of pollution control systems.[70]

The example of rare earth elements and lithium again highlights that the potential for environmental harm rests not with the mineral in question, but with the quality and depth of knowledge in mining practices, oversight, planning and scientific understanding. On the basis of the available evidence, there is little doubt that the unregulated or poorly regulated mining of, for example, rare earths and lithium, are, today, responsible for more severe environmental impacts than the regulated mining of uranium in Australia. Efforts are warranted to bring all mining to the highest practicable standard. Such efforts, by industry, governmental agencies and activist organisations, should be preferentially directed to the areas of greatest need and concern based on the available evidence, not on prevailing popular concerns relating to a given mineral.

There is no doubt that minerals such as lithium and rare earth elements will continue to be vital as renewable energy systems continue to grow worldwide.[71] Based on the experience of other mining and metal extraction industries, practices and governance will likely evolve beneficially in those parts of the world where they are currently below standards considered reasonable today. All parties should direct efforts to accelerate these processes.

6 Conclusion

In the vital practice of extractive mining, all practices for all minerals have the potential for negative environmental impacts. The most serious of these impacts can be closely tied to inferior practices, inadequate planning, insufficient oversight and a failure to properly apportion long-term financial responsibility.

However there is little to link such potentially serious impacts to the specific pursuit of mineral uranium. In reviewing literature relating to the environmental impacts of the major Australian uranium mines it is apparent that the standards, conditions and expectations relating to both uranium mining and mining in general have changed dramatically from the early, under-regulated era (pre-1980s), through to the early modern era (1980s) with continuing evolution to the present day (1990s and 21st century).

Regulation and mining practices continue to evolve. The Rum Jungle mine is a prime example of mining from the under-regulated era that has led to ongoing difficulties in rehabilitation relating to acid rock drainage of metals (including uranium, but with the most serious consequences relating to other metals).

The Mary Kathleen mine and in particular, the Nabarlek mine provide examples of better planning and important evolutions in practice, including monitoring of the sites and comparisons of rehabilitation performance with initial expectations. They provide a stark comparison to earlier standards.

The depth and breadth of scientific literature pertaining to the environmental performance of the Ranger Uranium mine indicates a step-change in approach. Literature suggests that environmental knowledge has been an important element from the outset, with continual study and evolving practice. The oversight of the Office of the Supervising Scientist provides additional transparency. Indications from scientific literature to date are that environmental impacts of this mine have been well controlled. The mine presents a far-lesser risk to the sensitive local environment than non-mining risk factors such as invasive species and climate change.

The large and complex operation of Olympic Dam stands apart as a poly-metallic mine that may well operate through to the end of the century. As with Ranger mine, literature indicates the transition to the modern mining era with greater planning and scientific research underpinning operations. Managing large volumes of above-ground tailings remains part of the challenge.

The practices of ISR mining at the Beverley/Honeymoon uranium mines stand out as particularly low-impact mining, with minimal surface disturbance and the prospect of swift and simple remediation. These practices are not limited to uranium however they have been well applied to uranium mining in these particular locations.

By contrast the contemporary international boom in rare earth and lithium mining is, in some major production regions outside Australia, reminiscent of the earlier era of mining. Lower standards are, unfortunately, common in developing countries, and the production from these regions will likely lead to long-term challenges in environmental remediation and management.

Overall this review indicates that the standard and type of mining practice, not the mineral, is the major distinguishing characteristic between good, satisfactory and poor environmental outcomes. This literature review suggests that contemporary mines of any type in Australia will come into being in an era of high and continually evolving standards of practice. This is not an argument for complacency, but an observation that, with determination, the potential negative impacts of extractive mining can be managed and the chances of satisfactory outcomes can be increased.

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