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ENVIRONMENTAL ASPECTS OF URANIUM PROJECTS

ABSTRACT

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The management of environmental aspects in uranium projects is in many ways no different to the management of environmental aspects in any heavy metal mining project. But there are important differences that need to be borne in mind if permitting issues and long term legacy issues are to be minimized. These differences include public perception of radioactivity and radioactive materials, the fact that uranium has daughter elements that themselves pose environmental hazards by virtue of their toxicity and longevity and the need to measure the effectiveness of controls through both dose as well as concentration. This paper highlights the author's experience with environmental management on a number of well known uranium mines and covers the management of stockpiles, heap leach facilities, waste dumps, tailings and effluent containment facilities as well as the mining area, plant area and transport routes. Expericences gained from consulting to these operations have been summarised to provide pointers to potential environmental management requirements for new projects.

1 INTRODUCTION

Uranium mining is emotive. The slow development of uranium mining in Australia bears testimony to this fact. But while the public and regulator concerns are real and valid they tend to be overblown by the perception that radioactive materials and radioactivity are pervasive once exposed and cannot reliably be contained. The impact of radioactivity is measured in terms of dose rather than the more commonly understood concentration and intake but there are established thresholds for dose just as there are for concentration and therefore it is appropriate to manage according to dose just as it is to manage according to concentration. Allowable dose levels are commonly based on research carried out and published by the US Nuclear Regulatory Commission (NRC) and incorporate the stochastic nature of radiactive dose and response.

A further factor influencing public and regulator perception of uranium mining is past experience particularly as regards the mining of uranium in the 1940's when the race was on to develop the atom bomb. Sheltered by the war effort and, probably, a poor understanding of the impacts of uranium mining, the mining operations in the US, Australia and other locations around the world tended to be poorly planned and there was little consideration of legacy issues. Governments of countries affected by this mining have spent large fortunes tidying up these mine sites and rendering them safe as well as defending themselves against third party claims for contamination impacts beyond the mine sites.

And with the environmental revolution of the 1970's the pendulum has swung with, some may argue, some over-correction particularly as regards legacy. In the sections below the broader range of environmental issues pertinent to both operational as well as closed mines will be reviewed. But first it is useful to elaborate on the metallurgical processing approaches commonly adopted for uranium ore.

2 URANIUM PROCESSING CONSIDERATIONS

Uranium can be mined using conventional underground or open pit mining techniques or by insitu leach (ISL). ISL is feasible where the ore body is sufficiently porous to allow the migration of reagents through the orebody to dissolve the uranium and where this can be carried out without significantly affecting the groundwater beyond the mine boundary. No ore is mined during ISL.

Uranium is soluble under both acidic as well as alkalinic conditions. The decision on whether to extract uranium under acid or base conditions depends on the host geology and the setting of the mining project. The majority of uranium processing operations adopt sulfuric acid leach but there are a number that make use of a sodium bicarbonate alkaline leach where the ores are high in carbonate. Where the host rocks in acid leach operations are slightly alkalinic the leaching reactions continue in the tailings delivery pipelines as well as on the tailings storage facility (TSF) itself. The acid is progressively neutralized with a concomitant loss of residual dissolved uranium, acid and coupler reagents such as iron and manganese which are added to the leach process. From a processing point of view it is therefore vital to maximize the recovery of supernatant liquor on the TSF as any water that becomes seepage will be neutralized. In an alkaline leach operation the reagents are not lost. In this case maximization of the recovery of supernatant liquor is essential not only to maximize the recovery of residual dissolved uranium but also to preserve the reagents which are usually significantly more costly than those used in acid leach operations.

Leaching of mined ore may take place in a heap leach operation or through a tank leach operation. Both of these processes require that the ore be crushed and screened. In the case of heap leaching operations the residue comprises “ripios” or spent ore that is ultimately flushed with water to remove as much of the residual reagents as possible. This flushing may take place regularly, in the case of re-usable heap leach pads, or at the end of operations, in the case of a static heap leach pad. In the case of a tank leach operation the ore is milled and the residue comprises sandy or sandy silt tailings which is stored in a TSF.

Both methods of processing will result in poor quality process liquor as this will contain not only the residual dissolved uranium but also the daughter elements as well as any other heavy metals which may have been dissolved in the process such as lead, cadmium, vanadium primarily as salts. Indeed salinity levels may exceed that of sea water.

So it is that regardless of the method of leaching of the ore there are significant financial incentives to reduce the volume of process liquor discharged onto the TSF. This is good for environmental management but there are residual issues as discussed in the next section.

3 THE ENVIRONMENTAL ISSUES

Environmental issues commonly found on conventionally mined uranium projects as a result of both mining and extraction may be summarized as follows:

- Potential surface water contamination as a result of surface water runoff from the stockpiles, heap leach facilities, waste dumps, processing plant, process and reclaim water containment dams, or a TSF. This contamination may not only be as a result of radionuclides but may include salinity generated in the uranium processing as well as, potentially, acid rock drainage caused by oxidation of sulfides in the host rocks.

- Potential groundwater contamination as a result of spillages or seepage from the processing plant and process and reclaim water containment dams as well as seepage through stockpiles, heap leach facilities waste dumps, and the TSF. Again, this contamination may not only be as a result of radionuclides but may include salinity generated in the uranium processing as well as, potentially, by acid rock drainage caused by oxidation of sulfides in the host rocks.

- Excessive water use as a result of concerns about competing ions in the supernatant water and seepage recovered from the TSF and their impact on uranium extraction efficiency.
- Dusting from open pit blasting operations, road traffic, the TSF and the waste rock dumps.
- Radon gas emission from the open pit, waste rock dumps and the TSF and the potential radiological dose imposed on surrounding communities as a result of wind dispersion of the gas.
- Ammonia gas emission from the final product recovery process.
- Occupation of the mine site both during operations as well as after closure by animals in the food chain, and, potentially, by people.
- Public use of contaminated materials such as scrap metal from the processing operations as well as waste rock and tailings which may be used as building construction materials.
- Spillage of reagents brought onto the mine site.
- Emissions from reagent preparation facilities such as sulphuric acid plants.
- Spent hydrocarbons.
- Spillage of the final product during transport off site to the export terminal.

Since ISL uranium mining does not entail the excavation of ore or waste rock the environmental issues associated with this mining revolve around protection of the groundwater beyond the mine boundary, and the dissolved uranium recovery facilities at surface.

It would not be uncommon for regulators to insist on a full year's worth of background monitoring of dust and radioactivity levels as a pre-cursor to finalising the environmental permit applications.

Prior to and during operations it will be necessary to monitor plants, animals and humans accessing the mine site or living within 10km of the mine site so as to build up a baseline of information on the relationship between source and receptor of the contamination and its potential progression through the food chain. This will be essential for environmental management but also to ensure that the data is available to address any claims made against the mining company.

The above environmental issues and their management are further discussed under the headings below.

4 STOCKPILE, HEAP LEACH FACILITIES, AND WASTE DUMP ASPECTS

In addition to the issues of potential nitrate leaching (from the explosives) and acid rock drainage that would require consideration on any mining project the issues that will affect stockpiles, heap leach facilities and waste dumps on a uranium project are likely to relate to:

- Dusting both as a result of wind erosion of the landform as well as haul truck traffic. In this case the dust will likely contain radioactive minerals.
- Leaching of radioactive minerals and dispersion of these into surface as well as sub-surface water.
- Erosion of the landform by rainfall and the resulting dispersion of radioactive minerals.
- Visual impact of the landform which tends to be stepped and regular compared with the surrounding environment.

Mitigation measures for the above potential impacts include:

- Seepage and surface water cut-offs to capture potentially contaminated water that percolates through and out of the landforms.
- The incorporation of surface water drainage systems to minimise contact of the surface water runoff with the landform materials.
- Application of haul road dust control measures such as regular watering or the use of dust inhibitors.
- The use of suitably sized crest bunds and cross bunds on step-backs to ensure that sediment eroded from the slopes is prevented from escaping the confines of the landforms.

- Adopting landform geometries that can be cost effectively modified to blend in with the surrounding topography.

5 MINING AREA

The principal environmental aspects for the mining area relate to dusting generated by:

- Blasting when wind or ventilation causes the dust to drift beyond the confines of the mining area
- Mucking
- Hauling

These issues apply to both underground as well as open cast operations although, environmentally, they are significantly more severe in the case of open cast mining. They do not apply to ISL mining which is significant advantage of this mining method.

Mitigation measures include:

- Minimising the extent to which mine infrastructure is located down-wind of the open pit
- Using water for dust suppression around the muck piles
- Using water or other dust fixing agents on the haul roads.

6 CRUSHING AND SCREENING

The environmental aspects associated with crushing and screening relate primarily to dusting and water management. Crushing and screening operations are inherently dusty. Where water is used for the control of dusting and for wash-down of the crushing and screeing plants this water is contaminated and needs to be captured and re-used after settling out suspended solids. Dusting from live stockpiles requires careful management and the strategic location of buildings and warehouses so as to make sure that these are not located within the dominant wind directions.

Mitigation measures for the potential impacts include:

- Spraying of the ore during crushing and screening with the collection and re-use of spray water in the processing plant or on roads for dust suppression after settling out the suspended solids.

- Covering live stockpiles particularly where the stockpile comprises finely crushed ore with a high dusting potential.

7 URANIUM PROCESSING PLANT

The uranium processing plant will generally include the following components:

- Milling (unless the operation is a heap leach operation)
- Leach reagent preparation. In the case of sulphuric acid leach this may entail a sulphuric acid plant or the provision of storage for acid shipped in. In the case of alkaline leach this may entail the dissolution of reagents with water.
- Leach (in tanks unless the operation is a heap leach operation)
- Separation of the pregnant solution from the solids using belt filters, Roto scoops, hydrocyclones, thickeners etc.
- Ion exchange
- Solvent recovery
- Final product generation – usually as a powder which implies drying and a ventilation stack.

The environmental issues and the appropriate mitigations that are generated by the above components include:

- Spillage especially during plant crashes or shut-downs for maintenance. These are mitigated by the provision of concrete flooring and bunding around the plant with associated water and solids recovery systems such as drainage trenches, sumps, ponds and pumps, for the recovery of water, and access for bobcats for the recovery of solids. Would be prudent to include a geomembrane liner under the concrete under the wet components in the processing plant as well as to ensure that ponds are double lined with leakage detection/collection systems.
- Gaseous emissions from the leach tanks as well as from final product recovery. Mitigations for these focus on ventilation and elevation.

8 TAILINGS MANAGEMENT ASPECTS

There is an increasing interest in adopting "dry" storage of tailings by means of stackers and conveyors. The drivers for this lie in the fact that the liquor within the leached slurry contains valuable components such as residual dissolved uranium acid (or alkaline) reagents and other additives such as ferric. Recovery of these components can sometimes offset the additional cost of filters that will be required to bring the tailings to a conveyable water content. However, the costs associated with filtration are strongly dependent on the particle size distribution of the tailings and, if the tailings are fine and poorly draining, filtration costs increase significantly.

Notwithstanding the adoption of "dry" disposal it will still necessary in the majority of projects to ensure that the tailings are placed on a geomembrane liner equipped with seepage control systems to ensure that rainwater that percolates through the tailings is drained from under the TSF, contained within lined collection ponds and reused in the processing plant.

Where "dry" disposal is found to be non-viable there is, in most cases, significant merit in opting for high density tailings management as this will still significantly reduce the volume of water sent to the TSF and water losses and seepage heads on the liner would be minimised.

Environmental issues that would need to be mitigated for uranium tailings stored in a lined TSF would typically include:

- Spillages from delivery pipe and reclaim water pipe breaks
- Seepage and flow from underdrainage layers incorporated into the TSF at the time of construction of the initial starter works.
- Dusting off the crests and dry beaches and dispersion in to adjacent land areas.
- Dusting off dried out pond areas where capillarity in the fine tailings in the pond areas draws salts to the surface. These are usually finer than PM10 and usually have elevated radionuclide concentrations.
- Radon emission from the dry areas of the TSF.
- Groundwater contamination as a result of tears in the lining under the TSF.

- Erosion of the tailings and dispersion down water courses.
- Visual impact

Mitigating measures that are usually incorporated are:

- Bunding and lining of all pipe routes and trenches that convey slurry and contaminated water.
- Application of dust controls at the leading edges of the TSF to minimise dusting. The most effective dust control measures are those that prevent the first grain of tailings from being mobilised. Measures may comprise chemical dust inhibitors or natural materials such as soil or rock sheeting.
- The use of windrows on tailings beaches and across pond areas. These can be formed using a grader where access permits or using windbreaks made of shade cloth or movable windrows made up from wooden or metal frames. Where water is not in short supply dusting can also be controlled by spraying.
- Progressive covering and rehabilitation of the side slopes of the TSF.
- Diligent quality control on the construction of liners and good protection of the liners after installation.

9 WATER AND EFFLUENT MANAGEMENT ASPECTS

In the case of acid leach facilities there are likely to be at least three categories of water on the mine and around the TSF:

- Fresh water will be required for application in flocc dissolution, pump gland service, potable water and other critical processing applications.
- Process liquor will be generated through the leach and uranium extraction process and this will be pumped to the TSF with the slurry. This will have a pH of around unity and will contain valuable dissolved components such as residual dissolved uranium (unless it is neutralised) and will constitute the majority of the supernatant liquor to be recovered from the pond area on the TSF.
- Seepage water that will have a pH between 4 and 7 if it has seeped through deposited tailings. This seepage water will be high in dissolved salts and will, on exposure to atmosphere result in the formation and deposition of

hydroxides which will foul up storage facilities and calcify pipes. In particular they will calcify and block underdrainage systems if these are not maintained in a submerged condition at all times.

In the case of an alkaline leach there will be at least two categories of water. Fresh water and process liquor which will remain largely unchanged when returned from the TSF either as supernatant liquor or captured seepage water.

Environmental issues that will emerge from water and effluent management on uranium projects will be:

- Degradation of fresh water
- Depletion of fresh water resources as a result of inefficient re-cycling of water, process limitations and evaporation.
- Leakages from water and effluent containment ponds due to the high hydraulic heads on the liners in the ponds.
- Spillages from effluent containment ponds due to high rainfall or poor control on the mine water balance.

Mitigation measures that can be incorporated to minimise the impacts of the above issues are:

- Careful management of the water balance both in terms of water quantity as well as in terms of water quality to ensure that the worst acceptable quality of water is used at all times in the various parts of the uranium processing plant thereby minimising fresh water input.
- Careful management of wetted areas on the TSF so as to minimise evaporation losses.
- The use of double liners in reclaim ponds with leakage collection systems between the liner layers so as to minimise water loss.

10 REAGENT IMPORT

Reagents will include sulphuric acid, for acid leach, or caustic soda and sodium bicarbonate, in the case of alkaline leach. These will need to be transported in significant quantities on a daily or weekly basis depending on the buffer storage facilities. These products are not environmentally friendly and allowance needs to be made to address spillages along the reagent importation route. Where possible transport routes should avoid communities and should preferably be by rail or dedicated pipeline which would be located in servitudes that can be isolated from the surrounding environment by appropriate bunding.

11 FINAL PRODUCT TRANSPORT AND EXPORT

Generally the final product comprises a powder, “yellow cake” that is transported in 200 litre drums which are loaded into containers. Under these circumstances the risk of spillage is relatively low but there will be poor publicity each time a container is dropped either along the route as a result of an accident or at the port. Appropriate management of the containers will be essential if the fall out from the publicity is to be minimised.

12 CLOSURE AND LEGACY ASPECTS

While operation of uranium projects require diligent environmental management it is after closure that the real impact of environmental obligations come together in the form of legacy issues. Closure and legacy issues are significantly more severe in the case of uranium projects than for most other minerals due to the radioactivity of the solids and effluents as well as the radon gas emitted by the solids. Not only does access to the residual mine site by the public need to be prevented long after closure but it is also vital that dispersion of radoactive materials beyond the confines of the mine site be controlled over the long term. This applies to reclaimed and recycled metal and building materials which first need to be de-contaminated of radioactive materials but it also applies to abandoned stockpiles, heap leach facilities, waste dumps, TSFs and effluent containment facilities.

In the US, uranium mine operators are bound by legislation[1] that stipulates *“In disposing of waste byproduct material, licensees shall place an earthen cover (or approved alternative) over tailings or wastes at the end of milling operations and shall close the waste disposal area in accordance with a design which provides reasonable assurance of control of radiological hazards to (i) be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years, and (ii) limit releases of*

[1] Criterion 6-1 in Appendix A of the NRC regulations US Atomic Energy Act of 1954, as amended (68 Stat. 919), title II of the Energy Reorganization Act of 1974, as amended (88 Stat. 1242), and titles I and II of the Uranium Mill Tailings Radiation Control Act of 1978, as amended (42 U.S.C. 7901)

radon-222 from uranium byproduct materials, and radon-220 from thorium byproduct materials, to the atmosphere so as not to exceed an average release rate of 20 picocuries per square meter per second (pCi/m^2s) to the extent practicable throughout the effective design life determined pursuant to (1)(i) of this Criterion".

This places two important constraints on long term closure, one relating to the security of a cover to a tailings or waste storage facility, and the other relating to the efficiency of that cover in limiting the release of radon-222. As far as this author is aware these criteria have been applied to uranium facilities in South Australia where population levels are exceedingly low and land use severely restricted by climatic conditions.

Covers need to be effective in inhibiting the migration of radon gas and, depending on the nature of the soil may need to be 2m or more in thickness if public dose modelling shows that the long term dose rates may exceed those recommended by the NRC and other local standards. But these covers also need to be able to withstand erosion. The development of gulleys in the cover as a result of the accumulation of surface runoff is likely to be the constraining factor in developing the specification for the cover. This is because gulleys will lead to the exposure and dispersion of radioactive materials while the rest of the cover remains essentially intact. It is therefore vital to be able to demonstrate the long term performance of the cover from a gulley formation perspective. Fortunately there are long term models available but, like all models, these are very much dependent on the input parameters and the reliability or calibration of these parameters.

If monitoring indicates that dust from the mining operation has escaped beyond the mine site it will be necessary to make arrangements to scrape the dust and surficial soils together and truck them back onto site for containment.

Effluent management after closure will require a commitment to potentially tens of years of management of the seepage from the TSF as the mound of saturated tailings within the TSF drains down. Thereafter there will need to be an arrangement whereby the seasonal drainage from any abandoned stockpiles, heap leach facilities, waste dumps and TSFs will need to be managed. Over the long term it may be anticipated that whatever percolates into these landforms will ultimately be discharged to the environment either at surface, if the facilities are lined, or sub-surface if the facilities are not lined. This means that serious consideration needs to be given to the minimisation of net percolation in to the landforms and this will inevitably lead to the consideration of store and release covers and possibly even the placement of a liner medium over the top of the landform as was done as part of the UMTRAP work carried out in the US in the 1990's.

It may be possible to route effluent to the open pit, in the case of an open cast mining project. If it can be demonstrated that the open pit will not fill and potentially spill or significantly leak into the surrounding groundwater systems it may be feasible to drain effluents to the open pit thereby minimising long term pumping management. This will not be without its problems as frequently the effluent from these landforms is high in hydroxides which tend to precipitate in channels and calcify pipelines. Such drainage routes would therefore best be covered to minimise exposure to air, and significantly over-designed to allow for the inevitable effects of the precipitation.

Monitoring of surface and groundwater quality would need to continue over tens of years to be able to demonstrate that the facilities are reliably unlikely to contaminate beyond the boundaries of the mine site. Monitoring would also need to extend to covers and demonstration of their long term integrity.

Contaminated soils under the processing plant, together with non-recyclable plant waste such as concrete would need to be excavated and removed to a lined facility or to the open pit. The excavations for these materials would need to be backfilled with uncontaminated soils.

It may be prudent to set up baseline monitoring of the health of employees and communities around the mine site prior to establishment of the mine and to continue with this monitoring during operations as well as into closure. The effects of radiation are stochastic and time dependent and the risk of real issues emerging long after closure, or of claims that will be difficult to refute without appropriate data, will be significant.

It will be nearly impossible to stop animals from entering the mine site. Where these drink contaminated water and then leave the site there is a risk that the contamination will enter the food chain. It will be necessary to demonstrate that this will not be an issue after closure though appropriate source and receptor modelling based on data accumulated during the operations.

In the case of insitu-leach uranium operations it will be necessary to demonstrate that residual reagents within the mined out orebody will not enter the food chain by degrading groundwater.

At closure it will also be necessary to rehabilitate reagent importation routes as well as product export routes so as to ensure that all defunct infrastructure is removed and contaminated soils are excavated, removed, and replaced with uncontaminated soils.

13 SUMMARY AND CONCLUSION

All mining requires careful consideration of environmental aspects the significance of which is dominated by the nature of the ore being mined and processed. This is particularly true in the case of uranium mining where contamination occurs not only as a result of solids and dissolved elements but also through radioactivity and gas emission. This paper has briefly described common uranium extraction methods with a focus on the resulting environmental effects of these methods and then highlighted the key environmental issues that need to be addressed. The issues have been elaborated on through the consideration of the key components of a common uranium mine and potential mitigation measures that would enable the control of the environmental aspects have been identified. The importance of baseline monitoring of both people and the environment prior to the commencement of mining operations as well as during mining operations is highlighted. It is noted that while monitoring and control is logical during operations these are as important after closure. Specific aspects that need to be considered at closure as well as potential methods for dealing with these have been described.

Provided the considerations set out in this paper are appropriately addressed, however, it is considered that there is no reason that uranium mining should be regarded as any less safe, environmentally, than the mining of other minerals and metals that are of lower toxicity.