7. PROPOSED RECLAMATION AND DECOMMISSIONING PLANS

7.1 Introduction

The decommissioning of any mine and its associated structures, equipment, waste dumps and other facilities, has the primary goal of reducing emissions of possible harmful substances and rehabilitating the land so that it becomes suitable for alternate uses. Secondary goals include ensuring that the site remains safe for human use and instituting such remedial actions as may be necessary to ameliorate unsightly or visually intrusive features caused by the mining activity. In the normal course of events, appropriate decommissioning measures for mines are generally accepted without undue argument. In stark contrast, however, society's perceptions of the environmental dangers and risks associated with the nuclear issue have mandated that the decommissioning of uranium mines be attended to with the same degree of care that is afforded to the disposal of nuclear wastes (Kalin, 1988). The current approach is to adopt the ALARA (As Low As Reasonably Achievable, with social and economic factors taken into account) principle (Kalin, 1988).

The great difficulty and high cost of reclaiming mine facilities which were designed and operated without decommissioning and reclamation in mind has fuelled international concerns that all mining plans must contain appropriate provisions for decommissioning. Indeed, it has become almost universally accepted that the granting of mining permits prior to startup is dependent on the inclusion of an appropriate decommissioning plan.

In common with other uranium mines, the Rössing Uranium Mine has developed a generalized decommissioning policy which is refined regularly as technology improves, to suit the specific conditions pertaining at the site. The Rössing policy provides for on-going reclamation as portions of the facilities are no longer needed; successful reclamation of the old exploration and construction camps, are examples. In addition, several on-going studies are under way to investigate particular options for specific sections of the mining operation. Ultimately, an effective site-specific decommissioning plan will permit restoration of the site to appropriate standards.

7.2 International Approaches to Mine Decommissioning and Closure

International approaches to mine closure differ between the major uranium producing countries, reflecting their different site conditions and levels of public concern (Kalin, 1988; Robertson & McPhail, 1989). Very often, a particular standard or control measure that is suitable for one site or country may be entirely unsuitable for another (Robertson *et al.*, 1987). This feature has an important bearing on the choice of particular techniques and standards that are appropriate for Rössing's situation. Ideally, the decommissioning objectives and standards chosen for the Rössing Uranium Mine should be in accord with internationally accepted standards, though modified to suit the local conditions and specific impacts of the mining operation.

International concerns relating to the decommissioning and reclamation of uranium mines centre on the control of particulate dispersion, radon emissions and gamma radiation, contamination of groundwater and vegetation, and visual impacts. Of these, the first two are of prime concern.

In the United States of America, simplified prescriptive reclamation measures were developed for certain critical elements such as a minimum depth of cover over tailings and a radon emanation rate below 0.07 Bq m^{-2} sec^{-1}. These prescriptive values were widely criticized as being inappropriate, inadequate or financially burdensome (Robertson & McPhail, 1989) and were never enforced by the Nuclear Regulatory Commission due to intervention by the US Congress (Dames & Moore, 1984b).

In 1983, radon release standards for uranium mine tailings issued by the USEPA set a limit of 0.74 Bq m^{-2} sec^{-1}, with the requirement that the reclamation design be effective for up to 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years (Dames & Moore, 1984b; Robertson & McPhail, 1989).

While no such numeric limits have been set in Australia, Canada, Namibia or South Africa, an unspecified degree of reclamation is expected to prevent radionuclide releases which could possibly result in public exposures in excess of respective standards. Public exposure risks are therefore an integral part of the selection of appropriate reclamation and decommissioning standards (Robertson & McPhail, 1989).

In Canada, where many uranium mines are located in remote areas of sparse population, it is accepted that there is a commensurately low risk of exposure (Kalin, 1988; Robertson et al., 1987; Robertson & McPhail, 1989). This has resulted in the acceptance of reclamation standards that are considerably less stringent than those being applied to the reclamation of abandoned US uranium tailings impoundments located in more populous regions (Robertson et al., 1987). Similar considerations should also apply in the case of the Rössing Uranium Mine due to its remote location in a desert environment.

7.3 Choice of Guidelines for the Rössing Uranium Mine

In the absence of direct legislation promulgated by the Government of Namibia, the Rössing Uranium Mine has adopted a set of protective criteria for both its own employees and the public at large (Dames & Moore, 1983b, 1984b). For radiation exposure, these criteria are based on either the recommendations of the ICRP (International Commission on Radiological Protection) or those adopted by regulatory agencies in other countries with an extensive uranium mining/milling industry (Dames & Moore, 1984b).

Rössing has adopted the objective of reducing wind-blown tailings dust levels and stabilizing the tailings dam. This will have the added advantage of reducing radon emanations from the tailings dam to levels that will be in line with other international standards and which are considered to be appropriate given the location and climatic conditions that prevail at the mine.

Gamma radiation levels at the Rössing Uranium Mine are within international standards (A.W.J. Jooste, personal communication). Operational practices are such that possible exposures to gamma radiation will be further limited by the thin alluvium and rock covers planned for the tailings dam.

In view of its desert location, it is anticipated that no beneficial land use other than possible recreation can be envisaged for the area surrounding the mine site after decommissioning. Adequate restrictions will have to be implemented to limit public access to the site so as to prevent unnecessary exposure to low levels of radiation.

7.4 The Rössing Open Pit

On completion of mining at the Rössing Uranium Mine, no extensive decommissioning measures are anticipated for the open pit. Such residual uranium ore as is exposed in the pit or its walls may be checked for radiation and covered with a shallow layer of waste rock if needed. The pit edge should also be surrounded by a reasonably substantial and resistant berm composed of soil or waste rock to prevent accidental entry of vehicles over the lip of the open pit.

Speculation that the open pit could be re-filled with waste rock, as is the practice in some far smaller open cast coal mines and quarries, is unrealistic. The time, effort and cost involved in transporting waste rock back to the open pit would approach the entire cost of removing the rock in the first place. Similar considerations would mitigate against the use of tailings as a filler for the open pit. Indeed, the impacts of transporting either material would far exceed in-place stabilization (Dames & Moore, 1984b). In addition, transporting tailings to the open pit would require the use of additional water and increase the risk of groundwater contamination.

7.5 Waste Rock and Marginal Ore Dumps

The waste rock is hard and durable and the waste rock dumps are expected to remain stable without significant slumping. At mine closure, the waste rock dumps are expected to fill much of Dome and Pinnacle Gorges and the level of radioactivity is expected to be approximately equal to background levels (Dames & Moore, 1984b). Therefore, no recontouring or re-shaping of the waste rock dumps is deemed necessary (Robertson & McPhail, 1989). Stock piles of high calc, unused high grade ore and other marginal grades of ore should be covered with waste rock. A large quantity (to be determined) of waste rock will be needed for reclamation and stabilization of the tailings dam surface.

7.6 Tailings Dam and Seepage Control

The tailings dam presents possibly the greatest problem for any reclamation and decommissioning activities at the Rössing Uranium Mine. Concern for the long term impacts of the tailings dam are due principally to the long half-lives of the two major radiological constituents, thorium-230 and radium-226 (with half-lives of 80000 and 1620 years, respectively; Table 3.3). In addition, radon-222, the short-lived gaseous daughter product of radium is constantly emitted from the tailings dam surface. The tailings dam therefore represents a long-term source of radioactive material (Dames & Moore, 1984b).

At closure, the tailings dam will contain some 540 million tonnes (Table 5.1) of materials containing naturally occurring radionuclides. The radiological concentration of thorium and radium in the tailings has been estimated (Dames & Moore, 1984b) to amount to some 3.8 Bq g^{-1}. The total activity due to the entire contents of the tailings dam at closure can therefore be estimated as 2.035 x 10^{15} Bq each of thorium and radium. The total activity due to the entire contents of the tailings dam at closure can therefore be estimated as 8 x 10^{15} Bq. Due to the long half-life of radium (1.63 x 10^{3} years), an insignificant amount of radon would grow-in.

Cover tests with a variety of materials of differing thicknesses have shown that even a 15 cm thick layer of alluvium can reduce any high radon emissions from the dry tailings surface to within 0.74-1.48 Bq m^{-2} sec^{-1}, the target guideline adopted by the Rössing Uranium Mine. This efficiency is increased when a layer of waste rock is added. Given the remote location, lack of nearby human habitation, the desert environment and the rapid dilution of radon in air, it appears that a thin layer of alluvium and sand will be sufficient to meet the proposed radiation limits. The desert environment and extremely low rainfalls make the US and Canadian requirement for a permanent vegetation cover both inadequate and inappropriate.

The gamma ray flux (exposure) on the surface of the tailings dam is controlled by a complex series of interactions within the tailings material. Earlier estimates (Dames & Moore, 1984b) have indicated that even a shallow sand cover of some 0.30 m can reduce the gamma flux by at least an order of

magnitude. Thus, the cover material used to restrict radon exhalation from the tailings dam will also serve to reduce gamma radiation.

Wind and, less frequently, water erosion, represent the two major mechanisms for the dispersion and transport of particulate and radiological material from the tailings dam. In the case of water, the infrequent rainfalls usually occur as discrete storm events and the runoff generated can cause both sheet and gully erosion.

Clearly, therefore, it is essential that any cover placed on the tailings dam should be sufficiently robust to withstand the erosive effects of both the episodic storm events and the very high wind speed that are commonly recorded during the winter months. Tests at Rössing have shown that a 150 mm layer of coarse-grained alluvium will rapidly develop a typical "desert pavement" appearance as the finer fractions are blown away. Steeper slopes require a cover of rip rap or waste rock, with carefully contoured faces and rock-lined channels to direct runoff into nearby water courses (Robertson & McPhail, 1989).

Particulate material that has been dispersed prior to stabilization of the tailings dam may have to be cleaned up. The extent of such clean up measures will depend on the type and extent of the control measures which are implemented during future mining operations (Robertson & McPhail, 1989). The sooner that control measures are implemented, the less will be the requirement for clean up of the surrounding environment.

On decommissioning, the tailings pond will be drained and allowed to dry out. Some settling and cracking of the surface layers can be expected as the phreatic surface drops. This will cause settling of large areas of the planned alluvium and rock cover, necessitating the placement of additional material to prevent erosion within the cracks. The anticipated settling of the surface can and should be planned for (Robertson & McPhail, 1989).

Seepage discharges to Dome, Pinnacle and Panner Gorges will continue for a considerable length of time, the flow rates declining exponentially with time (Robertson & McPhail, 1989). Therefore, it can be expected that the current system of interception wells and cutoff trenches with pumps will have to be continued for a considerable period of time before they can be discontinued. During this period, it will be necessary to evaporate the pumped back water, preferably in lined evaporation ponds on the surface of the tailings dam (Robertson & McPhail, 1989). Public access to the tailings dam should be prevented to avoid disturbance of the cover material and reduce the risk of possible health hazards. The planting of perennial vegetation should only be considered in those areas where seepage water lies at relatively shallow depths. No vegetation is likely to survive for long periods on the upper surface or slopes of the tailings dam.

7.7 Uranium Processing Plant and Mine Buildings

The requirements for closing and decommissioning the uranium processing plant and the mine buildings at the Rössing Uranium Mine have been described in detail by Dames and Moore (1984b). These measures are considered appropriate and, to avoid undue repetition, they will only be described briefly here.

For all practical purposes, it has been assumed that no buildings or structures will remain on site following closure of the Rössing Uranium Mine. Therefore, all structures will require decontamination and must be demolished or dismantled for use elsewhere. Material that cannot be readily decontaminated may be disposed of by burial in the tailings dam. Decontamination procedures may vary, depending on the level of contamination and the type of structure. Specific procedures will need to be determined on a building by building basis (Dames & Moore, 1984b).

As examples of the types of work required to ensure effective decontamination, Dames and Moore (1984b) cite the following:

- Bulldoze the coarse ore pile clean, clean out all crusher bins and bulldoze fine ore pad clean;
- Hose down the entire plant, removing all solids from the crushing plant, leach tanks, thickeners, etc. and pump liquid to the tailings dam;
- Treat all remaining aqueous solutions containing uranium through the continuous ion exchange plant and pump barren solutions to the tailings dam;
- Place all ion exchange resins into drums and sell, or dispose of them in the tailings dam;
- Burn off all organic residues;
- Clean out, drum and ship out all final product. Clean down final product plant in accordance with established decontamination procedures;
- Dismantle entire plant, removing all salvageable machinery to a specific location;
- Demolish foundations, bulldoze and cover with native material. Rubble should be disposed of either in the tailings dam or open pit;
- Treat the acid plant in exactly the same way as the final product recovery plant, except that any remaining pyrite can be sold.

In addition to the above, Dames and Moore (1984b) recommend that from all areas where tailings have been used as fill, the tailings should be excavated and transported to the tailings dam. A considerable quantity of material is involved, amounting to approximately 74000 m^3. Other areas which might also require decontamination include those under or adjacent to the crushers and conveyers and the area in and around the final product recovery plant.

The decommissioning of the works and facilities must be accomplished in a manner which will minimize exposure of workers and prevent the release of either contaminated facilities for public use or the release of contaminated material to the surrounding environment (Dames & Moore, 1984b).

7.8 Monitoring Requirements

As is the case during the normal operation of an uranium mine, monitoring forms a very important component of any decommissioning procedure. Typically, the elements making up a decommissioning monitoring programme will be carried over from any operational monitoring programme undertaken during the life of the mine. Normally, such a decommissioning monitoring programme will start functioning prior to closure and will continue after decommissioning activities have been completed, until the radiation data indicate acceptably constant or decreasing trends. The actual duration of monitoring will depend on site specific conditions, but is very likely to be measured in decades rather than years. In addition to the radiological monitoring programme, a non-radiological monitoring programme would also be conducted. The environmental monitoring programme will be augmented during decommissioning activities by the continuation of all personnel monitoring programmes including personnel dosimetry, bioassay, and any others that may be deemed necessary (Dames & Moore, 1984b).

7.9 Site Security

The entire mine complex, including the open pit, waste rock dumps and tailings dam should be fenced to restrict access by people and animals; appropriate multilingual notices should be placed at regular

intervals, particularly where natural access routes exist. These notices should carry an explicit warning that entry to the premises is forbidden in law and that trespassers will be prosecuted. The location of the fence and any access routes required for post-decommissioning monitoring should be defined at the time of mine closure. Access should be restricted to key-holding mine-appointed officials involved in monitoring or remedial work and regulatory officials who may require independent measurements to be made. Under no circumstances should members of the public be allowed free access to either the open pit or the tailings dam. All persons entering the site should be logged in an entry register, together with their times of entry and departure. Radiation-sensitive badges should be worn by all persons entering the premises.

Responsibility for maintaining site security and undertaking precautionary monitoring after decommissioning will depend largely on prevailing environmental concerns and on existing legislation. The allocation of responsibility after decommissioning of the Rössing Uranium Mine presents several problems since the company would, presumably, cease to exist. Ultimately, this issue will have to be resolved in a fair and equitable manner in the light of changes in environmental legislation which are taking place world-wide. Clearly, unnecessary or unreasonable constraints which cannot be met for technical or economic reasons will lead to the collapse of the industry and threaten the fabric of society (Down & Stocks, 1978). The overall objectives of environmental protection have been well stated by Burd (1971):

> *"The direction of change in environmental protection is toward more and stronger laws and toward more frequent enforcement of those laws. The goal of laws and enforcement is not punishment, assignment of blame, or payment of damages. The goal is the assurance that man and his social and economic activities will blend and conform to the laws of nature. This is society's problem".*

8. CONCLUSIONS

The enormous scale of operations at the Rössing Uranium Mine has largely dictated the extent and severity of the recorded impacts. Based on an evaluation of the available information and the findings of this report, the following conclusions can be drawn:

8.1 Pre-Mining Baseline

1. There is very little quantitative information available on the environmental conditions that existed at the site of the Rössing Uranium Mine before exploration and mining activities started in the early 1970's. Most of the information that is available is of a qualitative or anecdotal type. The exception to this generalization is the detailed geological information that was gathered in the process of proving the extent of the uranium ore-body at Rössing.

2. The Rössing orebody is unique in that it is the largest known deposit of uranium occurring in granite. The main deposit contains an average ore grade of 0.035% whilst uranium levels in the surrounding rocks are much lower. Background radiation levels at Rössing and in the surrounding areas are generally low and are within safe levels.

3. The scarcity of available water resources in the Namib Desert compounds the problems of mining low-grade (i.e. high tonnage) orebodies. A major proportion of the daily water requirements of the Rössing Uranium Mine have to be imported by pipeline from the Central Namib State Water Scheme (CNSWS). This scheme abstracts groundwater from aquifers at the mouths of the Kuiseb and Omaruru Rivers via a system of wells, and also supplies the domestic water requirements of local towns. Additional water supplies for the Rössing Uranium Mine are pumped from the bed of the nearby Khan River. Recent events indicate that the rates of water abstraction from the Khan River and the CNSWS exceed the recharge capacity of these aquifers. It is therefore essential that every effort be made to maximize the efficiency of water reuse at Rössing and reduce the freshwater demand as far as possible.

4. Ecological studies conducted in the Namib Desert have shown very clearly that the organisms of this area are specially adapted for existence in the harsh desert environment. The most noticeable component, the perennial vegetation, is either specially adapted to the infrequent rainfall or draws water from predominantly saline underground supplies. Each of the plant and animal populations in this desert environment tends to occupy specific types of habitats. Dry river valleys and steep rocky ridges offer the greatest diversity of habitat types and, consequently, contain the greatest diversity of organisms. Both the perennial vegetation and diverse rock formations in these areas provide vitally important refuges for the survival of other organisms. Natural patterns of infrequent and episodic rainfall cause dramatic changes in the distribution of plant and animal populations in this fragile environment.

5. Ecological studies conducted by the staff of the State Museum at Windhoek have demonstrated clearly that a remarkable variety of organisms exists in the area around the Rössing Uranium Mine. Several of the organisms collected by the State Museum staff are new to science, demonstrating the scanty knowledge that existed prior to their studies of the animal and plant populations around Rössing. Because of its overall similarity with nearby habitats along the Khan River, it can be assumed that similar populations of plants and animals were present <u>on</u> the mine site before mining activities started.

6. Prior to the start of mining activities, only one perennial water source existed in the Rössing area, namely the small permanent spring at Piet-se-Gat. Small ephemeral springs only flowed for short periods after rainfalls.

7. Prior to the start of mining activities at Rössing, the only "land use" in the area consisted of limited prospecting for semi-precious gemstones, small-scale mining of tin and copper, and the occasional utilization of the Khan River bed by off-road vehicle enthusiasts.

8.2 Current Mining Activities

1. Since the start of mining operations at Rössing, some 696 million metric tonnes of low-grade ore and waste rock will have been removed from the open pit by the end of 1990, at a rate of approximately 150 000 tonnes per day. Of this total, waste rock comprises approximately 450 million tonnes while the balance, 244 million tonnes, is made up of different ore grades. The waste rock has been dumped in designated dumping sites in Dome and Pinnacle Gorges, around the periphery of the open pit. Presently uneconomic ore grades are stockpiled on the waste dumps for possible future use. Virtually the entire tonnage of extractable ore (192 million tonnes) has been slurried to the tailings impoundment.

2. The acidic solution used in extracting uranium from crushed ore is also used to transport the tailings to the tailings impoundment. Acidic seepage from the tailings is largely neutralized by contact with marble formations underlying the tailings impoundment, precipitating most of the heavy metals in the process. Chemical data collected from boreholes located down-gradient from the tailings impoundment have shown that the seepage front has proceeded down Pinnacle Gorge, and is now located near the junction of Pinnacle Gorge and the Khan River. Seepage fronts in the upper portions of Dome and Panner Gorges have largely been contained by the system of de-watering wells. The quality of the seepage water is such that it will cause a deterioration of the saline underground water in the Khan River. Prior to the installation of cut-off trenches and de-watering wells in Pinnacle Gorge, a small amount of tailings seepage entered the Khan River. The cut-off trenches in lower Pinnacle Gorge now prevent this recurring. The existing system of de-watering wells and cut-off trenches appears to be adequate for preventing contamination of the Khan River. However, an unknown quantity of seepage also moves through fractures in geological formations. This should be quantified to determine whether or not additional protective measures are required.

3. The buffering capacity and chemical retardation capacity of the soils and rocks are finite and non-renewable. The available data are insufficient to base any estimates as to how long this retardation will remain effective. Contaminant break-out will occur when the available buffering capacity has been consumed.

4. Since mining started, additional permanent water sources have become available; in particular the seepage pond below the tailings dam and the seepage pool near the top of Panner Gorge. Seepage from the tailings impoundment has raised the local water table in Panner and Pinnacle Gorges such that the soil surface is occasionally damp and crusted with salts. The availability of additional perennial water sources has led to changes in the distribution of certain plants (particularly *Phragmites* reeds) and ground-dwelling insects and arachnids. *Phragmites* reeds lose large quantities of water via evapotranspiration each day, thereby placing a greater burden on the limited local water supplies.

5. No visible signs of chemical stress are evident on the vegetation growing along Pinnacle and Panner Gorges. It must therefore be assumed that the vegetation in these areas is able to tolerate the increased salt load due to seepage that is currently present in the groundwater.

6. An estimate of the annual average occupational radiation dose is 3 mSv year^{-1}, which is well below the limit of 20 mSv year^{-1} recommended by the ICRP. The contribution of the mining activities to the radiation dose at the town of Arandis is <0.6 mSv year, or about 10 % of their natural exposure.

7. Noise and vibration in and around the Rössing Uranium Mine have not had a marked effect on animal and bird populations. The greatest impact would appear to be on mine personnel; this impact can be reduced to safe levels with the use of appropriate safety equipment in areas of excessive noise and vibration.

8. The dispersion of dust and particulate material from the mining operations at Rössing presents a series of problems to mine management. The dispersion of radionuclides with the tailings dust during wind storms poses a hazard to both humans and natural plant and animal populations. Indeed, wind-blown tailings dust is deposited in the lee of every bush and rock, which in turn form the most important habitats or refuges for the region's plant and animal populations. Additional control measures are required to further reduce the quantity of wind-blown tailings. Deposits of wind-blown tailings in the areas closest to the south-western side of the tailings impoundment will need remedial action.

9. Virtually all of the areas disturbed during the exploration and development phases at Rössing have either been rehabilitated or covered by the present infrastructure. At present, (1990), the Rössing open pit covers an area of some 400 hectares, whilst the rock dumps in Dome and Pinnacle Gorges cover approximately 535 hectares. An additional 585 hectares is covered by the tailings impoundment and 125 hectares is covered by the mine plant and offices. A further 600 hectares have been affected by the construction of roads, powerlines, pipelines, fences, the airstrip, activities in the bed of the Khan River, Rössec and Namib Lodges, the town of Arandis and the predominantly Rössing-owned suburbs Tamariskia and Vineta in Swakopmund.

10. The total area disturbed directly or indirectly by mining activities at Rössing amounts to some 1900 hectares, (19 km^2); Arandis, Swakopmund and the Rössing Country Club account for an additional 3 km^2. It is conservatively estimated that an additional area of at least 6 km^2 has been directly affected by wind-blown tailings dust in the vicinity of the mine. This area of some 25 km^2 is small when taken in the context of the entire Namib Desert. However, in terms of its effect on the extent and distribution of habitat types and plant and animal populations, this area is enormous. Our scanty knowledge of the conditions that prevailed prior to mining prevents any categorical statement regarding the numbers and types of plant and animal communities affected. Nevertheless, the available evidence clearly suggests that the area around the Rössing Uranium Mine most likely contained plant and animal species that comprised rare or endangered communities. Whilst most of these species might also be expected to occur in similar habitats nearby, this cannot now be proved.

11. The remote location of the Rössing Uranium Mine and the general dust haze that characterizes much of the Namib Desert has limited the extent of visual intrusion in the horizontal plane. Further raising of the tailings impoundment will result in an intersection with the skyline and increase its visual intrusion. Stack emissions from the acid plant are normally very low and seldom cause unsightly clouds except during plant shut downs. From the air, both the open pit and the tailings impoundment are prominent and detract from the desert scenery. Further enlargement of these two structures will exacerbate their visual impact.

12. The development of the Rössing Uranium Mine has had an enormous beneficial effect on both local and regional socio-economic values. In particular, Rössing has made large contributions to the gross domestic product of Namibia and has earned valuable foreign exchange. At the regional level, the impacts brought about by Rössing are particularly visible, including the creation of several hundred job opportunities and the institution of several training schemes. In addition, the development of infrastructure, as well as extensive new housing schemes, hospitals, schools and recreational facilities has had a "ripple effect" throughout the region.

8.3 Future Mining Activities

1. During the remainder of the mine life (to the year 2018), it is estimated that an additional 1195 million tonnes of ore and waste rock will be removed from the Rössing open pit. Of this total, waste rock and sub-economic ore grades will comprise some 848 million tonnes, with the balance of approximately 347 million tonnes being economic ore. Based on these projections, it is estimated that the different impacted areas will increase in extent to a total of 3010 hectares or approximately 30 km^2. The open pit will increase in area by some 75% whilst the area of the tailings impoundment will increase by approximately 20%. In addition, the area covered by the waste rock dumps will increase by approximately 60%, filling the lower reaches of both Dome and Pinnacle Gorges. This will accentuate the loss of plant and animal habitat experienced to date.

2. Elevated dust, noise and radiation levels will cause the most important negative impacts. Every effort will have to be made to reduce dust and radionuclide dispersion. Improved tailings disposal practices that are currently being explored will allow greater stabilization of the tailings impoundment surface and thereby reduce dust levels.

3. Improved tailings disposal techniques will result in increased water recirculation within the mine plant as well as smaller losses due to evaporation and seepage. This will reduce the mine's freshwater demand on the Central Namib State Water Scheme.

4. Seepage of rainwater through the dumps of waste rock and sub-economic grade uranium ore will pose a potential problem through contamination of the Khan River. An additional cut-off trench and de-watering well will probably be needed at the lower end of Dome Gorge.

5. The increased height of the tailings impoundment can be expected to increase the hydraulic pressure exerted on the local groundwater, accelerate the rates of movement of seepage fronts, and thus accentuate the possibility of groundwater contamination. However, the proposed paddock system for tailings disposal should reduce the volumes of water (and thus the hydraulic head), minimizing the seepage losses.

6. If the buffering capacity of the rock and soils beneath the tailings impoundment becomes exhausted, there are likely to be severe negative impacts on any plants growing in the path of the seepage fronts. This aspect requires careful consideration in future.

7. The groundwater monitoring programme has provided, and will continue to provide, information essential to understanding the groundwater characteristics of the area and evaluating the effects of remedial measures.

8. The construction of a dam in the bed of the Khan River will improve the rate at which the Khan River aquifer is recharged by flood waters. In turn, this will allow Rössing to abstract greater quantities of saline water from the Khan River bed and thus reduce the freshwater demand. However, the full extent of the direct and indirect impacts that might arise should be evaluated before construction commences.

9. A comprehensive reclamation and decommissioning plan will have to be drawn up for the Rössing Uranium Mine. This plan will have to incorporate appropriate measures such as those embodied in the ALARA (As Low As Reasonably Achievable, with social and economic factors taken into account) principle. The desert environment and the mine's remote location indicates that there is a relatively low risk of public exposure to elevated radiation levels. Reclamation standards should take this aspect into account. Reclamation standards derived for the Rössing Uranium Mine should be far less stringent than those applied to, for example, abandoned uranium tailings dams in the United States of America.

10. Public access to the mine property must be restricted after closure of the mine. The open pit will require fencing and warning notices should be attached to the perimeter fence around the mine property. Access to the mine property should be limited to mine officials engaged in monitoring studies and regulatory officials who may require independent measurements of dust and radiation levels.

11. After mine closure, a routine monitoring programme will be required to evaluate any possible changes in the groundwater due to seepage from the tailings impoundment. In addition, monitoring of ambient dust and radionuclide levels will be required at selected points on the mine property and nearby towns.

9. RECOMMENDATIONS

As a result of the observations and conclusions of this report, the following recommendations are made:

1. The existing environmental monitoring programmes which evaluate dust and radiation levels must be continued throughout the remaining life of the mine. These routine measurements provide information that is essential for remedial management actions. Particular attention must continue to be focused on the extent to which dust and radionuclides are dispersed from the tailings impoundment, ore stockpiles and the open pit.

2. Consideration should be given to the installation of some form of wind shrouding at areas where high dust levels are generated. Prior evaluation of such an option must include the assessment of wind loading levels during east wind storms.

3. The existing groundwater monitoring programme must also be continued throughout and beyond the remaining life of the mine. Particular attention should be focused on determining the extent of movement in the seepage plume from the tailings impoundment. The quantity of seepage moving through fractured rock should also be evaluated. In addition, the possibility that the Khan River could be contaminated by seepage from the waste rock and sub-economic ore dumps in lower Dome Gorge should be evaluated. If warranted, an additional cut-off trench and de-watering well should be installed at the junction of Dome Gorge and the Khan River.

4. Water-saving measures must continue to be applied wherever possible. This should include application of the paddock discharge principle at the tailings impoundment, while process water should be recycled as far as is technically and economically feasible. With the paddock discharge system, the surface area of exposed water must be minimized to reduce evaporation losses. Eradication or control of the *Phragmites* reedbeds below the tailings impoundment would greatly reduce evapotranspiration losses. This can be achieved by selective cutting procedures and the construction of drainage channels below the tailings impoundment to lower the water table.

5. The current rates of saline water abstraction from the Khan River should only be continued with the understanding that this water resource is being over-exploited. Should the Khan River aquifer continue to receive low recharges from upstream, abstraction at current rates will eventually lead to permanent loss of the perennial vegetation along the river bed. The time scale over which this could occur cannot yet be calculated.

6. The feasibility of constructing a dam wall across the Khan River should be evaluated as a matter of urgency. Such a structure could greatly increase the quantity of water in the Khan River aquifer. This would provide an enormous increase in the quantity of saline water available to the Rössing Uranium Mine and significantly reduce the mine's daily freshwater demand.

7. The plant and animal populations present in areas which will be covered by the expanding waste rock dumps and tailings impoundment must be evaluated. Based on the findings of such a study, a decision can be taken as to the desirability and feasibility of translocating rare or endangered species to safer sites nearby. These surveys should be as quantitative as possible in order to extend our understanding of the fragile desert environment around Rössing.

8. The buffering capacity and chemical retardation properties of the soil and rock formations beneath the tailings impoundment should be investigated. This will provide a sound basis for predictions as to when this buffering activity will no longer retard the movement of certain chemical contaminants. In turn, this will assist management to determine whether or not additional de-watering wells will be required.

9. Current efforts to stabilize the surface of the tailings impoundment and reduce the extent of wind-blown dust must be continued and expanded. Physical structures, such as Wabco tyres and reed fences, and chemical sprays have already contributed to reducing dust levels. Further tests should be conducted with chemical sprays, either alone or in combination with alluvium layers of different depths.

10. Revegetation of the tailings impoundment with either alien or indigenous species is unlikely to succeed unless regular irrigation is provided. This option therefore does not offer a long-term solution and merely contributes to water consumption. The use of some form of physical ground cover, such as netting, is likely to as effective as plant cover.

11. The Environmental Impact Statement (E.I.S.) drawn up for the Rössing Uranium Mine should be considered as a "living document" and form the basis of regular evaluations of environmental impact during the remainder of the mine's life. These evaluations or audits could take the form of short annual surveys, where the preceding year's data from the environmental monitoring programme is evaluated. Where necessary, specific studies of critical components could also be undertaken by Rössing staff. These could then be used to update the E.I.S. so that it will at all times contain relevant, up-to-date information to guide management actions.

12. A detailed and comprehensive decommissioning and reclamation plan should be drawn up for the Rössing Uranium Mine. This plan must include provision for final stabilization of the tailings impoundment and waste rock dumps, as well as details of appropriate environmental monitoring. Particular attention will have to be given to intercepting seepage streams from the tailings impoundment and returning these for evaporation, preferably in a lined dam. Reclamation of the mine plant and buildings will also have to be included, as will appropriate measures to limit public access to the site. The reclamation plan should also include details of clean-up operations to remove radioactive tailings dust from the surrounding countryside.

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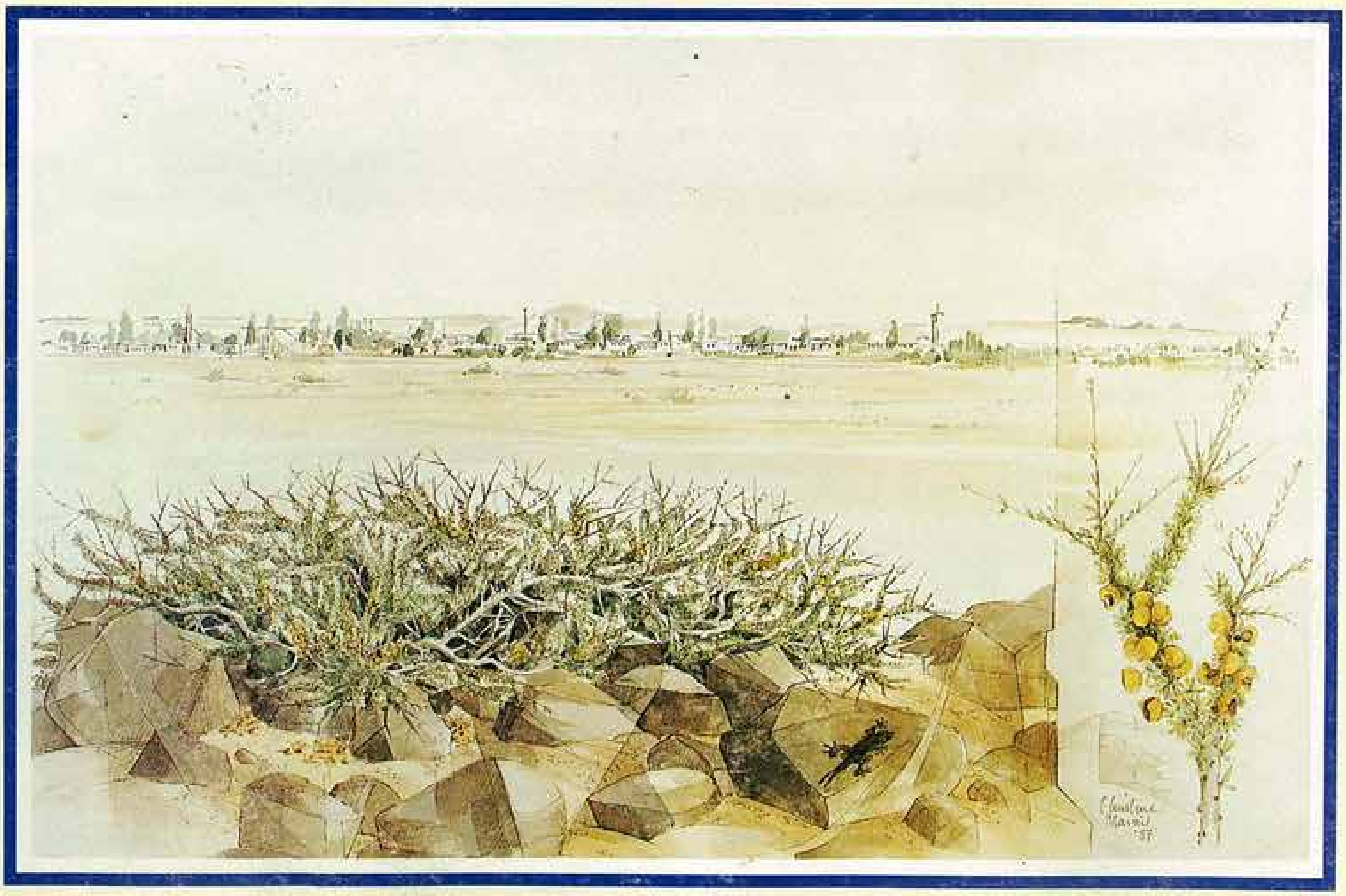

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