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Information Document: Review of an Independent Scientific Panel of the scientific issues associated with the proposed mining of uranium at Jabiluka in relation to the state of conservation of Kakadu National Park. Undertaken between 22 April and 13 May 1999

Background

This Information Document contains the peer review by an independent scientific panel of the *Assessment of the Jabiluka Project – Report of the Supervising Scientist to the World Heritage Committee* (WHC/99/CONF.204/INF.9C) as requested by the twenty-second session of the World Heritage Committee (Kyoto, Japan 30 November – 5 December 1998)

Other relevant documents

WHC-99/CONF.204/5	Reports on the state of conservation of properties inscribed on the World Heritage List (see section concerning Kakadu National Park, Australia)
WHC-99/CONF. 204/INF.9A	Report on the mission to Kakadu National Park, Australia, 26 October to 1 November 1998
WHC-99/CONF. 204/INF.9B	Australia’s Kakadu – Protecting World Heritage. Response by the Government of Australia to the UNESCO World Heritage Committee regarding Kakadu National Park (April 1999)
WHC-99/CONF.204/INF.9C	Assessment of the Jabiluka Project: Report of the Supervising Scientist to the World Heritage Committee
WHC-99/CONF.204/INF.9D	Written independent expert review of the advisory bodies (IUCN, ICOMOS and ICCROM) concerning the mitigation of threats posing ascertained and potential dangers to Kakadu National Park by the Jabiluka mine.

Review of an Independent Scientific Panel of the scientific issues associated with the proposed mining of uranium at Jabiluka in relation to the state of conservation of Kakadu National Park.

Undertaken between 22 April and 13 May 1999

The review was carried out by a panel established through the International Council for Science (ICSU) at the request of the World Heritage Committee of UNESCO. The Independent Science Panel was composed of four scientists (Appendix 1).

Review of an Independent Scientific Panel of the scientific issues associated with the proposed mining of uranium at Jabiluka in relation to the state of conservation of Kakadu National Park

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Executive Summary

The Independent Science Panel established by ICSU has assessed the scientific and technical issues contained in the review by the Australian Supervising Scientist relevant to the proposed uranium mine site at Jabiluka, and in supporting documents to this review.

The panel reached the conclusion that the Supervising Scientist's Report and its supporting documentation contains new information and analyses that enable a scientific assessment to be made of the impact of the Jabiluka Mine on the World Heritage values of Kakadu with a much greater degree of certainty than formerly. However, the panel consider that there remain issues on which they would require further information before they could reach a firm judgement. There are additional measurements and analytical activities that the panel would wish to see undertaken. The uncertainties and requirements for additional work are presented in the report and in the recommendations.

1. Introduction

The study that the Independent Panel of Scientists (Appendix 1) has undertaken has been essentially based on the Supervising Scientist's Report and supporting documents to that report. The panel have carried out its work diligently but with the limitation that all of the information it would have wished for, was either not readily available, or was too voluminous to digest in the time at its disposal. Insights have also been restricted by not having visited Jabiluka.

We have met our Terms of Reference in that we have:

- provided an assessment of the scientific issues contained in the Supervising Scientist's review;

- identified a number of issues we consider may impact on World Heritage values at Kakadu.

We reached the conclusion that the Supervising Scientist's Report and its supporting documentation contains new information and analyses that enable a scientific assessment to be made of the impact of the Jabiluka Mine on the World Heritage values of Kakadu with a much greater degree of certainty than formerly. However we consider that there remain issues on which we would require further information before we could reach a firm judgement. There are additional measurements and analytical activities that we would wish to see undertaken. The uncertainties and requirements for additional work are presented in the report and in the recommendations in Section 6.

We would wish to receive the responses to our report from UNESCO and the Supervising Scientist.

2. Hydrological Modelling and Prediction, Impact of Severe Weather Events, and Retention Pond Capacity - Chapters 3, 4, 5.1 and 5.2 of SSR

2.1 Introduction

These three sections of the SSR have scientific issues that are closely interrelated and we have therefore considered them together in this review. The following supporting documents of the SSR are also addressed here:

> *Hydrometeorological Analysis relevant to Jabiluka* – Commonwealth Bureau of Meteorology (RHU)
> *Climate Change Analysis relevant to Jabiluka* – Jones *et al* CSIRO (RCC)
> *Hydrological Analysis relevant to the Surface Water Storage at Jabiluka* – Chiew & Wang, University of Melbourne (RCW)

These chapters and supporting documents are aimed primarily at the design of the pond to retain surface water, ground water and process water in the total containment zone, water which it is assumed would otherwise drain into watercourses forming part of the East Alligator River. The main issues are:

1. The estimate of the annual rainfall at Jabiluka not likely to be exceeded, on average, on more than one occasion in 10,000 years (referred to as the 1:10,000 annual exceedance probability {AEP}).

2. The estimate of the evaporation from the water surface of the pond.

3. The estimate of the evaporation in the mine in relation to the size of the pond.

2.2 Rainfall Data

The RHU (Table 1) sets out the rainfall, evaporation and climate data that are available in the area, while the locations of the stations where the data are captured are shown in Fig 2.1 of the RSS. We consider it very fortunate that so many data are available—comparisons with similar locations in the tropics in other continents would generally reveal far fewer stations, with each of these having much shorter records. The existence of an 88 year record of rainfall (1911 to 1998) at Oenpelli, 25 km north east of Jabiluka is particularly important: records from other sites, although closer, are briefer. The RHU comments that 'there was very little missing data in the Oenpelli daily rainfall record and the 88 years of data is an excellent record'. It also comments on the method of infilling missing data.

The RHU and RCW make no reference to the nature of the site of the raingauge at Oenpelli and any site history which may have revealed changes which could have affected the reliability of the record. Nor are there similar remarks for any of the other sites. However, the sites must meet the Bureau of Meteorology requirements, or the Bureau would not have employed the records from them in its report (RHU). None of the reports mention raingauge errors, such as evaporation from the gauge or the effect of wind, both of which would tend to make the recorded rainfall less than the amount actually reaching the ground (Sevruk 1989). Nor is there comment on the site of the evaporation pan at Jabiru Airport, probably an exposed site which would lead to over-estimates of evaporation by the Class A pan.

It is probable that these over-estimates are compensated for in the pan factors that are applied to the monthly pan totals.

In view of the likely underestimate of the rainfall at Oenpelli and other sites, we recommend that consideration be given to increasing the design AEP annual rainfall for Jabiluka by 5% unless there is evidence to the contrary. This would mean a reassessment of the storage capacity of the retention ponds but the likely increase in volume would be modest.

2.3 Tests of the Rainfall Data

Comments are made in RSS and RHU on the choice of data sets used to estimate the 1;10,000 AEP annual rainfall. We consider that the reasoning behind the selection of the record for Oenpelli is sound. The monthly and annual rainfall totals for Oenpelli from 1911 to 1998 are presented in Appendix A of RHU. A high correlation between the Oenpelli and the Jabiru records is shown to exist for the monthly and annual totals and the monthly correlation is demonstrated in Fig 3.2.1 (RSS). Comparisons of certain statistics for these two rainfall stations are given in Table 3.2.1. (RSS) and these show close agreement.

The Wasson *et al* Report asserts that the distribution of annual rainfalls at Jabiru Airport is skewed (page 17) and draws conclusions about the estimation of the 1:10,000 AEP based on this assertion. However, when the Oenpelli annual rainfall record was tested for normality (RHU), the tests proved that these annual totals are close to a normal distribution; the coefficient of skewness is very small. This normality is also shown in Fig. 1 (RHU), where the ranked values plot as a straight line, as of course they should. The annual totals for Jabiru Airport were also found to be close to a normal distribution.

A test was also made (RHU) to establish whether the total of 2223 mm recorded at Jabiru in the exceptionally wet year of 1975-76 (the highest of the plotted points in Fig 2) was an outlier. The method used for this test was not described, but the result reported in RHU indicates that this was not the case. Hence this total and the 2011.6 mm recorded at Oenpelli in the same year should not be excluded from the analyses. Rather this rainfall was estimated to have an AEP of 1 in 88 years in the Jabiru record. There seemed to be an assumption in the RHU that the presence of an outlier might distort the analyses. Such an outlier would seem to represent an exceptionally strong monsoon, one which might have a return period of several hundred years. In a sequence of 88 annual rainfalls, a small number would be expected which would represent AEPs greater than 1:88.

There is reference (RSS) to a study using the CUSUM method, which revealed that ‘the period 1960 to the mid 1980s was one of significantly higher average rainfall than the long term mean’. Presumably this phrase should have said: ‘the period 1960 to ……. significantly higher annual rainfalls than the long term mean’. This finding was repeated at a number of other stations and RSS suggests that the short term (88 year) Oenpelli record which is dominated by this period of higher than average rainfall, has a mean for the 88 years which is higher than the long term mean. We consider that this suggestion could be misleading without the evidence to support it from a longer rainfall record.

2.4 Estimation of the 1;10,000AEP Annual Rainfall for Jabiluka

Estimation of events with a long recurrence interval from a short record is a topic which has attracted a considerable amount of attention over the years. There are large numbers of papers in the literature dealing with this matter, especially for events of a short duration such as floods and heavy rainfalls (Cunnane 1989). The method (IE Aust 1987) employed in RHU and RSS is a recognised one, more than likely based on Chow's (1951) general frequency formula. No doubt it produces estimates which are little different from those others would produce. This point is demonstrated in RSS which compares an estimate made by the Beard (1960) method with the result obtained by the Institution of Engineers of Australia (1987) method. The important point is that the estimate of the 1;10,000 AEP annual rainfall is limited more by the available data than by the choice of the method of analysis from amongst those that can be applied. In this regard it is fortunate that such a long and apparently reliable rainfall record is available at Oenpelli.

There is a suggestion in the Wasson *et al* Report that a synthetic record of rainfall should be generated, with the implication that a synthetic record would give a better estimate of extreme events. The result of such an exercise is mentioned in RSS (page 25) where a figure of 2702 mm was obtained from a daily rainfall distribution generated by a stochastic model from the Oenpelli record. Neither this method, nor the application of storm generating models, extended to a year would seem more realistic than the RHU and RSU quoted estimates of the 1:10,000 event derived from the recorded rainfalls. These are the values of 2460 mm ± 170 for Oenpelli and 2610 mm± 320 for Jabiru, with the Oenpelli figure being employed for Jabiluka. However, the synthetically generated data set based on the Oenpelli records leads to a slightly higher AEP and as this data set has been used in determining the retention pond capacity it would appear appropriate to use this higher AEP.

If measurements have not already started we would recommend that measurements of rainfall and Class A pan evaporation are commenced as soon as possible at Jabiluka so that comparisons can be made with the Oenpelli rainfall and Jabira evaporation records.

2.5 Pond Evaporation

The performance of the US Weather Bureau Class A pan against lake evaporation was the subject of a large number of studies in the 1950s and 1960s and fewer in recent years. Comparisons of its performance against other types of pan and tank have also been made, together with comparisons with estimates of evaporation obtained by the so called indirect methods, such as combination formulae, for example that of Penman (1948). A range of pan factors (or coefficients) have been developed to try to take account of differences of surface, site and season, with values between 0.6 and 0.8 being the most commonly applied. Such factors are discussed in RSS and RCW with values from 0.64 to 0.70 being advocated for the dry season and 0.75 to 0.95 for the wet. We consider that the application of these factors is appropriate to the design of the pond.

Some of the errors occurring in pan-based estimates of evaporation are mentioned in the Wasson Report (page 18) and their probable origin, particularly the difference between gauge measured and pan measured rainfall. The Wasson Report calls for use of solar radiation records in a combination formula as a check on pan values. That this was carried out and that good agreement was found is reported in RCW and RSS (page 26), although few details of the comparison are given. RSS and RCW also mention a number of other studies, some leading to the confirmation of the pan factors used in those reports. The inverse relation between evaporation and rainfall is a further point discussed in the Wasson report, particularly the bias which the neglect of this relationship would impart to the design. It is clear from the discussion of this relationship in RCW (see Table 3.1 and Figs 3.5 and 3.6) that it has been sufficiently investigated. We welcome the conclusion in RSS that ‘a linear relationship between evaporation and rainfall is to be incorporated into future water management modelling’ (page 29).

2.6 Mine Evaporation

The decision on whether or not to install heaters, blowers and humidifiers in the mine seems to rest with the mining company - a matter of economics rather than science. However the impact of the extra four hectares of pond, should the decision be not to install the system, is a point for consideration with the other landscape and visual amenity matters. This increase in pond size is dismissed rather lightly by RSS in relation to the size of the disturbed area. However, an increase of 45% in the area of the pond could make it a more significant feature of the environment. The Wasson *et al* Report is more concerned with the design of the ventilation system and some of these concerns are dealt with in RSS. Our opinion is that the relationship between pond and pan evaporation is the critical one.

2.7 Evidence of Past Severe Weather Events

The evidence put forward by Wasson *et al* that climate in the region has been significantly different over the past 10 000 years and that it may be significantly different over the next 10 000 years is accepted by all. However, the SSR dismisses this as an issue in that all tailings will be returned underground and that contaminated material will only be in surface repositories for periods of approximately 30 years. This being the case we accept, on the basis of the information available to us, that there will be no long term containment of the tailings on the surface and a problem of surface contamination from this source will not arise.

2.8 Probable Maximum Precipitation Events

Wasson *et al* suggest that the design method used to assess the height of bunds to prevent local water entering the Total Containment Zone is satisfactory but is concerned that the correct rainfall intensity should be used. The SSR has examined two methods to determine the 6 min PMP. The two estimates lie within 4%. The SSR recommendation is that the higher value from the Bureau of Meteorology (RHU), of 1380 mm/hr be used in the detailed design of the local drainage works. We find this acceptable. The estimation of PMPs is at best a difficult exercise as the Bureau Report (RHU) acknowledges. However the Bureau claims to have produced the best estimate given the limitations of data and the methodology. We are in agreement with this statement.

It would be valuable to see what analyses have been undertaken from any rainfall recorder within the humid part of the Northern Territory and to compare the recorded most severe storms for durations from 5 min to 72 hr with the envelope curve in Fig 4 of RHU. We would recommend that the Bureau be asked to look at this approach and examine the envelope of the most severe recorded storms.

2.9 Climate Change

Much uncertainty and misinformation surrounds the issue of predicting climate change arising from the increasing concentration of carbon dioxide and other 'so called' green house gases in the atmosphere. The CSIRO Report (RCC) provides an excellent basis for the examination of this issue and it is appropriate that the SSR should have reviewed the implication of climate change in relation to the proposed mining operations at Jabiluka. The SSR uses the results from a number of internationally recognised atmospheric/ocean models that are used to predict climate change resulting from the increase in green house gases. The SSR identifies the difficulties in using such results and the uncertainties associated with them. It is therefore important that the results are considered as being preliminary. However, modelling methods are improving and we anticipate that over the next five years major advances will be made and the predictions from these models will be used with greater confidence. In the meantime, we consider it prudent to err on the safe side when using the results.

The results from the models were compared for both temperature and rainfall. For the Jabiluka region the temperature changes compare well (14%) between models. These predict an increase in temperature at Jabiluka by 2030 in the range of 0.35 to 0.8 C . The increase in temperature will lead to an increase in evaporation rates from the retention ponds but the SSR has been prudent and has recommended that this should not be taken into account in the design of the ponds.

Estimates of change in rainfall due to green house gas induced change have also been made. There is much less consistency between the model predictions here. The model predictions for the dry season of 2030 fall in the range of + 6% to – 50%. For the wet season the range is +1% to – 6%. The wet season changes are clearly the most important in relation to Jabiluka. If the model results can be accepted, such changes will be small with a worst case of 1% increase in rainfall. The SSR identified a trend in the Oenpelli Record (although it lies well within the historic variability and so is not statistically significant) which if extended would increase the annual rainfall from 2000 to 2030 by 4%. It is impossible to say whether the trend in the record represents a climate change signal or not at present.

On the basis of a 1000 year analysis of a stochastically generated data set based on the Oenpelli Record the SSR suggests that the trend is already incorporated in the generated data and there is therefore no reason to increase the design rainfall to account for a possible increase of 1% as indicated by the climate models. This conclusion is questioned as the stochastically generated data appears to have been based on the assumption of stationarity. The recommendation from the SSR in

Chapter 4 is that the new atmospheric modelling outputs will be kept under review and the design rainfall increased, if necessary, is, we believe, an acceptable approach. We were concerned therefore to read in Chapter 5.2 of the SSR that climate change impacts will be negligible and can be accommodated in the variability of the storage simulations. We do not accept this and consider that the SS should keep the predictions from the atmospheric models under review and the design of the retention ponds should be flexible so as to accommodate any increase in predicted runoff as necessary.

All of the atmospheric models being used to predict climate change indicate an increase in the intensity and frequency of storminess even though in some areas the average precipitation may decline. The SSR draws on analysis by Jones et al (RCC) which suggests that for the Jabiluka area over the period 2000 to 2030 the PMP may increase by 30%. We consider the SS to be prudent in making the recommendation that the PMP should be increased by this amount in the final design of the exclusion bunds which form part of the water management system at Jabiluka.

The contention that the 1960-84 rainfalls are higher than the average (see Fig 4.4.1) should be treated with caution. It raises the questions - what is the long-term mean? – which are the natural variations of climate and which are those due to human interventions? – what is there to say that the 1920-60 record was not drier than average and that the long term mean is best approximated by the 1960 – 84 record? The wetter 1960-84 record should not be used to argue that the long term average is lower.

2.10 Retention Pond Capacity (Chapter 5.2)

Wasson *et al* raised a number of important concerns in relation to the use of hydrological data in designing the retention ponds. For example, they:

- suggest that there is the need to generate a synthetic rainfall data sequence for use in simulation studies to determine the 1 in 10 000 year pond design capacity;

- identify the importance of establishing a relationship between rainfall and evaporation records; and

- point to errors in the calculation of evaporation in the exit stream of the mine ventilation.

The SSR has addressed the above issues in a systematic way and in particular through the study by Chiew & Wang. This study is based on a simulation analysis of 50 000 sets of 30 year daily rainfall and monthly pan evaporation data which have been stochastically generated. Such techniques are widely used in hydrological analysis and the statistical checks used on the generated data in comparison with the observed show it to be robust for design purposes. However, we have noted earlier that the rainfall data may be underestimated and we would therefore recommend reanalysis with a 5% increase in rainfall records.

In the simulation modelling Chiew & Wang (RCW) use what appear to be conservative runoff coefficients for a range of surfaces. This approach is acceptable but it would be valuable to attempt to validate these using hydrological observations at the Ranger Site.

Relationships between rainfall and evaporation were established and used in the storage model (see 2.5 above).

The SSR recognises that the evaporation loss in the ventilation shaft has been overestimated. The original values used in the first design could only be achieved by the use of a large humidifier. In the event of an expensive humidifier not being installed, an allowance to increase evaporation from the ponds could be made. The SSR recommends that in the detailed design of the Water Management System increased use of pond evaporation rather than enhanced evaporation from the ventilation system should be used. Careful modelling will be needed but the analytical tools are available. We therefore consider that the additional evaporation can be achieved by the use of larger retention ponds but this will increase the 'footprint'. The environmental significance of this will need to be considered.

There are some elements of the water management system that are not clear to us from the documentation provided. These are as follows:

(a) The mill requirement is given as 180 000 m3/year. What happens to this water? Does it evaporate or does it generate an effluent? And, if so, what is its disposal route?

(b) The ore wet-down and plant-wash water is small in comparison with the mill water, but how is it disposed of?

(c) Wasson *et al* refer to ground water inflow to the mine. What is the quantity of water involved? How will it be used and how disposed of?

(d) Have there been any simulations of the type reported in RCS carried out for Ranger Mine? If not, could these be undertaken. They should give an insight into the runoff coefficient, evaporation rates, etc, for use in the Jabiluka designs.

2.11 Overall Assessment

We consider that the meteorological and hydrological analyses that have been carried out and reported in the SSR overall follow good international practice. The rainfall and evaporation data have been used in a runoff model to develop a robust retention pond design method for Jabiluka .

We have raised a number of issues where we have been unable to make a judgement because information was not readily available to us.

We have recommended a number of measurements and analyses which should marginally improve the reliability of the hydrological predictions and design approach.

2.12 References

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3. Risk Assessment for the ERA Proposal – Chapter 5.3 to 5.4 of the SSR

3.1 Introduction

These sections of the SSR are concerned with a risk assessment resulting from releases of water from the Jabiluka site. The SSR makes reference to the supporting documentation:

> Protection of the environment near the Ranger uranium mine – Johnson & Needham (RPE).

The SSR, in considering environmental protection objectives, suggests that considerable quantities of water from the mine area could be safely discharged to surface water courses. However, in view of the concerns of local people the ERA proposal adopted a policy of containing mill and stockpile water and any material with a concentration greater than 0.02% uranium on the site during the working life of the mine. We are in full agreement with this approach.

These sections of the SSR thus consider the probability of failure of the water containment facilities under a range of situations such as extreme storm events or earthquakes leading to overtopping or collapse of the retention pond embankments. The impacts and risks to people and ecosystems arising from such extreme events are assessed.

3.2 Water Quality of Runoff from the Ore Stockpile

The ERA based their assessment of water quality in the ore stockpiles at Jabiluka on data collected from the Ranger mine. To allow for the higher concentrations of uranium ore at Jabiluka a concentration of uranium and other related radionuclides in the drainage water in excess of that for Ranger was used in the risk analysis. The concentrations of magnesium and sulphate selected also appear to be conservative values in relation to risk analysis. While we accept the approach that has been adopted it would have been useful to have had information to support these assessments and statements such as 'The information obtained from kinetic testing of a number of samples of the Jabiluka ore showed that, while a number of metals and metalloids were present in the ore at concentrations greater than the average in the earth's crust, none other than uranium was at a concentration that, under the general chemical environment of the ore stockpile, will present a threat to ecosystems or people beyond the mine site'. This statement was given with neither attribution nor justification. In the time available, we were not able to obtain a copy of Appendix B of the PER, an ERA review, although a request was made. The water from the ore stockpile will be held in the retention ponds. We were uncertain whether any allowance had been made for the effects that evaporation will have in concentrating contaminants in the pond.

3.3 Radiation Exposure of Members of the Public

We accept that, as a result of the extensive containment facilities that are proposed at Jabiluka, the probability of exposing members of the public to radiation doses from Jabiluka will be very small. We know that the SS has developed a model for Ranger. This model is then applied to the Jabiluka situation and the conclusion is reached that the water management system at Jabiluka poses an insignificant radiological risk to local people and people living downstream. We accept this assessment subject to evidence that the model is applicable at Jabiluka. Are the water management, hydrology and receiving waters at the two sites sufficiently similar so that this modelling transfer can be made? Uranium is chemically toxic and we assume that risks associated with, (a) soil ingestion, especially if the local people practice geophagia, and (b) dust inhalation, have been taken account of in the Ranger model. If not a risk assessment based on the chemical toxicity of uranium is required.

3.4 Impact on Aquatic Ecosystems

The SSR makes an assessment based on RPE of the impact of radiological and chemical exposure of aquatic organisms resulting from the Ranger Mine discharges. These studies were for fish and macro-invertebrates. We have reservations about the approach adopted here. The section implies impact (risk) on aquatic ecosystems but no ecosystem analysis has been carried out. The analysis relies on 'surrogates for the whole ecosystem'. Emphasis is given to the effects on fish in summary statements such as ' … some effects do occur in invertebrates, but adverse effects on fish would not be expected. Any adverse effects on invertebrates would be very short lived.' This conclusion assumes that there is no in-stream processing including biotic and abiotic uptake in the sediments of Swift Creek. Because the discharges of contaminated material would be of very short duration the assumption that the effects of biological recycling might be minimal would be acceptable but this would need to be clearly demonstrated. Without such a study the restriction of the analysis of the aquatic ecosystem to direct chemical and radiological toxicity towards a few species is unsatisfactory.

We accept the assessment of probabilities ascribed to overtopping of the pond, static failure of the pond embankments and earthquake risks. The estimation of radiation exposure of the public associated with such extreme events appears to be acceptable but, as indicated above, justification is required for these single species and as indicators of impacts on the whole aquatic ecosystem.

3.5 Contingency Measures

The proposal to have the means, under extreme conditions, to separate the poor quality water from the ore stockpile from that draining from the rest of TECZ is sensible and acceptable. Protecting the retention ponds with a properly designed spillway, as suggested in SSR, we would consider as essential. Partitioning the retention ponds and the installation of interconnecting spillways would reduce the risk of discharging all of the retention pond volume if an embankment were to fail (ie, it would be unlikely that all of the embankments would fail together). We consider that this should be examined at the detailed design stage.

4. Long Term Storage of Tailings – Chapter 6 of SSR

4.1 Introduction

The proposal considered in Chapter 6 of the SSR is to place all the tailings from the processing of the Jabiluka ore in the mine void or in specially excavated silos in the vicinity of the void. The detailed proposal for such containment has not been received but the SSR identified the principal environmental issues that need to be assessed as:

i. Containment of the solid tailings so that they do not represent a long term threat to the wetlands of Kakadu and
ii. Leaching of containment from the tailings, dispersion of the solutes in ground water and the potential impacts on the wetlands.

The SSR draws on the findings in a report on:

> The analysis of long term ground water dispersal of contaminants from the proposed Jabiluka Mine tailings repository – Kalf & Dudgeon (RGD)

The mine void and silos will be at least 100 m below the land surface and we accept the conclusion in the SSR that the tailings, once placed in these containment facilities, and sealed, would not present a threat to Kakadu as a result of erosion processes for some hundreds of thousands of years. However, the leaching of contaminants and their rate of dispersal in the ground water is recognised by the SSR as a potential issue and this is considered in some detail in both the SSR and in RGD.

4.2 Hydrogeology of the Area

A hydrogeological description of the area is presented in RGD. This covers the range of aquifers, their flow characteristics and ground water quality. As in most subsurface investigations the data is somewhat sparse and there is a wide range in the flow characteristics of the principal water bearing foundations as expressed through their permeabilities and dispersivities. The permeability values appear to have been determined from bore hole pumping tests and the range of values subsequently used in the modelling work should be acceptable for rocks of the type described. However, in the modelling work a normal distribution of permeability values was chosen for the Monte Carlo simulations, whereas it may have been better to have assumed a logarithmic distribution.

No mention is made of isotope measurements on the ground water samples or in stream base flow. The use of such measurements, eg, O18/ deuterium ratios can give an indication of ground water and base flow age. This may enable flow rates and bulk permeability values to be assessed for comparison with pump test results. It is recommended that if such measurements have not been made then a sampling and measurement programme should be put in place.

4.3 Solute Transport Modelling

The groundwater flow and contaminant transport modelling carried out for this review is simplified with several consequent limitations and, as such, represents essentially a first pass at the problem. This is explicitly recognised in the modelling report (RGD), but is perhaps not adequately acknowledged in the SSR. However, we consider that the general approach adopted is reasonable and, given the realistic choices of parameter values, should have produced a relatively robust picture of potential outcomes. Some areas where the limitations might be significant are given below.

We were encouraged to see Monte-Carlo simulations used to assess the uncertainty in the predictions. It would have been useful if the RGD had included cumulative probability plots. These would have indicated the range of possible outcomes and their relative probabilities. The median breakthrough plots really provide little more information than a single deterministic calculation.

The models as developed do not appear to be able to predict the regional flow of groundwater and the rate of movement of contained contaminants. That is, the time it takes natural recharge from the ground surface to move through the mine waste and aquifer systems and emerge in surface water courses or the sea. The time scale is likely to be many thousands of years but it is important that the models be modified so that the scale of the problem can be assessed. We found it encouraging that the movement of sulphate, and in particular, uranium, from the tailings waste in both the mine void and the silos is restricted to such short distances and at such low concentrations after 1 000 years. However, a modelling study to assess the movement over a much longer time period (possibly 10 000 years) and also to identify where ground water flows emerge, is also necessary.

4.4 Properties of the Tailings

The tailings are to be dry mixed with Portland cement prior to disposal. This mixture is expected to produce a permeability contrast two to three orders of magnitude less than the host rock.

The report is deficient in not providing chemical modelling results to demonstrate that future water-rock interactions will not compromise the silos' integrity and increase U mobility.

There is little attention in the SSR given to the geochemical reactions that may occur between the cement and tailings. This may well be covered by the ongoing research that is referred to in the SSR. The comments in the following paragraph may aid ongoing work.

It is stated that the cement grout will serve to lower the permeability of the tailings in the mine voids and silos, and hence reduce the potential for groundwater movement and will create alkali conditions which would help to retard heavy metal migration. We would agree with this. However, there appears to be little or no detailed information on the effects of alkali conditions on the tailings or host rocks.

Alkali porewaters associated with the grouted waste will migrate as an alkaline plume controlled by the local hydrogeological conditions. These are likely to react with the host rocks. The reaction rates and solubilities of many aluminosilicates are increased under alkaline conditions.

Models, coupling fluid flow and geochemical reactions, should be used to predict the development of the alkaline plume. Such modelling will need to consider what phases are likely to dissolve (eg, aluminosilicates) and what are likely to precipitate [eg, Calcium Silicate Hydrate (CSH), zeolites, ettringite, etc]. Such phases may also take up radionuclides within their structures and thus be a further retardation mechanism.

Changing mineralogy may result in changes in permeability, and hence, changes in fluid flow. Many minerals associated with alkaline conditions would precipitate and help to seal porosity and retard fluid flow. However, increased dissolution could lead to an increase in porosity and possibly enhanced fluid flow in the host rocks. It is the overall effect of these two competing processes that will be important. Other studies on alkaline plumes (relating to cementitious radioactive wastes) appear to favour a sealing of porosity.

The information given in the report on tailings solute composition used in the transport modelling does not mention solution pH. It is therefore difficult to make detailed comments on the high sulphate concentrations. However, it should be clarified whether the solute composition is for approximately neutral or alkaline conditions. If there are uncertainties in this, it is suggested that geochemical modelling (possibly allied to simple laboratory experiments) be undertaken to ascertain the porewater composition within the cement grout/tailings mixture.

The potential for high pH, high sulphate waters is important because of the possibility of ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}.26H_2O$) formation. Although this mineral only tends to form under very high pH conditions, it has a very high molar volume and is very good as sealing porosity. However, delayed ettringite formation can cause fracturing and other problems in concretes. Has thought been given to the possibility of this in the grout/tailings mixture?

Has consideration been given to sorption of the radionuclides on Fe and Mn oxides/hydroxides? It may be worth noting that information from other studies (relating to radioactive waste disposal) appears to show high sorption on these phases, and thus it may be an additional retardation mechanism.

4.5 Overall Assessment

Our overall view is that the SSR has correctly identified the principal risk from the buried tailings as that arising from the transport of contaminants in groundwater.

There are some uncertainties in ascribing aquifer properties for the modelling work but these are overcome by selecting a wide range of permeability and dispersion values and modelling groundwater flow and contaminant movement using a Monte Carlo approach.

The addition of cement has been used in other radioactive waste facilities and observations indicate that this may significantly reduce the permeability of the waste and contaminant mobility. Chemical interactions in the highly alkaline environment of the tailings and host rock need to be considered alongside the movement of the alkaline plume because under some unusual circumstances an increase in permeability may arise.

We are pleased to note that the preliminary results from the modelling show that the transport of uranium and radium away from the repository is very limited, even after 1 000 years and that the concentrations are very low. This would therefore not appear to present any foreseeable risk to the Kakadu environment. However the models, while robust, simplify the flow conditions and the possible tailings-paste/host rock reactions. We recognise that geochemical studies on the reactions of the paste are currently being undertaken. We recommend that three-dimensional groundwater models are run once new information on rock/water interactions is available and that these models should be extended to encompass regional groundwater flow and its contribution to surface waters.

5. General Environmental Protection Issues – Chapter 7 of SSR

5.1 Introduction

We note in section 7.1 of the Report that the SS has demanded a standard of environmental protection for mining activity in the Region which are seen as 'being among the highest in the world'. In view of the RAMSAR listed wetlands within the Kakadu National Park, it is appropriate that this should be the case. The work at the Ranger Mine has led to setting water quality standards and these have been accepted by the Australian and Northern Territory governments and given wide application. A range of aquatic species have been tested to establish which were the most sensitive to water from Ranger. This led to the choice of dilution factors for effluents. The SS reports that during the entire period of mining at Ranger there has been no detectable impact on larval fish, freshwater snails, fish migration and community structure, and macro-invertebrates or on the people living in the vicinity. We welcome this appraisal. The SSR states that the regulatory regime for Jabiluka will be strengthened and the retention pond arrangements and tailings storage facilities that have been proposed support that contention. We urge that this be done.

5.2 Jabiluka milling alternative

It appears from section 7.2 that if mining at Jabiluka is to proceed then the so-called 'Jabiluka milling alternative' (JMA) will be adopted. This is the option we have been examining throughout our assessment. We note reference in section 7.2 to the sandstone stockpiles and the prospect of discharge from them to Swift Creek. Measures will be needed to reduce sediment loads arising from these to background levels and we note that this has been recognised by the Ministry of the Environment. We seek some explanation as to how this will be done.

5.3 Extent of the ore body and mine life

We note in the SSR(7.3) that if the ore body is larger than anticipated and the mining were to continued beyond the proposed 30 year horizon, then under the JMA there would be no need for further assessment under the Environment Protection (Impact of Proposals) Act 1974. We consider the prospect of extending the life of the mine as a realistic possibility. Most of the probability analyses undertaken by the SS are based on a 30 year horizon and we believe that analysis should be repeated to test the sensitivity of impacts to a mine life of 40, 50 and 60 years.

5.4 Landscape – wide Analysis

We do not consider that the SS has adequately addressed the Jabiluka Mine in the land scale context (Rees & Wackernagel, 1994; Wackernagel & Rees, 1996). In view of the proximity of the mines to the Kakadu National Park a more comprehensive ecosystem scale study is needed. It should be recognised that the management of the Kakadu World Heritage area is best conducted at the watershed or landscape scale, and as the current plan is to add the Jabiluka lease area to Kakadu after rehabilitation, such an approach is critical. The environmental impact assessment for Jabiluka must consider the potential ecosystem effects of the movement of both contaminated and uncontaminated water, air, dust and animals within the mine site and across its boundaries, as well as the role of the Jabiluka and Ranger Mines within the larger landscape. A comprehensive risk analysis at the landscape scale should be done to show that the Kakadu park World Heritage Site will not be significantly degraded by the combined operation of the Jabiluka and Ranger Mines. How will plant or animal populations, habitats, resources, travel corridors etc be impacted by the Jabiluka Mine? The influence of the potential impacts of the Jabiluka Mine within the ongoing development of the Kakadu area, including Jabiluka, should also be assessed. While the water management plan (including the bore field) for Jabiru focuses on the mine site the question has to be asked as to what will be the impact of changing the water balance within the area on the ecosystem. We are unable to judge on the basis of the information provided. The assessment should be included in the land form/catchment study framework.

5.5 Rehabilitation and Monitoring

We were pleased to have an outline in SSR 7.6 of the rehabilitation objectives for Jabiluka . We also noted the progress that had been made at Ranger as described in the brochure 'Rehabilitation at Ranger', but without detailed information or a site visit we are unable to assess the level of success. We note reference to the Jabiluka rehabilitation fund and the Guarantee from the Department of Mines and Energy. Such arrangements are essential in such a sensitive area and assurance should be sought that the size of the fund would be adequate to any rehabilitation task. It will also be important to establish a commitment (possibly 100 years) to monitor surface water and ground water flow and quality and the ecosystem following rehabilitation. The monitoring programme would need to be periodically reviewed and extended or reduced as necessary.

5.6 References

Rees W E. & Wackernagel M 1994 *Ecological footprints and appropriated carrying capacity*. Pp362-3980 In *Investing in Natural Capital. The Ecological Economics Approach to Sustainability* A M Jansson, M Hammer, C Folke & R Costanza (eds), Island Press, Washington DC

Wackernagel M & Rees W 1996 *Our ecological footprint: reducing human impact on the earth.* New Society Publishers, Gabriola Island, GA

6. Recommendations

We recommend that:

1. because the rainfall measurements at Oenpelli may be underestimated due to wind effects etc and in view of the crucial importance of the rainfall record in terms of the design of retention pond capacity the rainfall record should be increased by 5 % unless there is any evidence to the contrary. The hydrological analysis, including the stochastically generated data , should be repeated using this enhanced rainfall data (2.2);

2. rainfall and class A pan evaporation measurements should be commenced at Jabiluka as soon as possible (2.4);

3. the predictions of climate change from observations and atmospheric models should be kept under review during the life of the mine and the design of the retention pond area should enable the storage to increase to accommodate a predicted increase in runoff should this be necessary (2.9);

4. the runoff coefficients used by Chiew & Wang in the runoff modelling should be validated on the basis of hydrological measurements from the Ranger site. The runoff models should be modified if necessary (2.10);

5. an assurance should be obtained that the uncertainties in relation to water requirements at the mill, effluent disposal routes etc have been adequately dealt with in the design of the water management system. Due to lack of information it is not clear to the Independent Science Panel that this was the case [2.10 (a to d)];

6. justification for the use of the Ranger 'Public Exposure Radiation Model' at Jabiluka is required. A risk assessment based on the chemical toxicity of uranium is needed with particular reference to (a) soil ingestion, and (b) dust inhalation (3.3);

7. the effects of biological recycling of contaminated material in the aquatic ecosystem should be investigated (3.4).

8. the design of the retention pond system should include consideration of the partitioning of the storage volume so as to reduce the risk of the total water volume being discharged should an embankment fail (3.5);

9. isotope measurements should be used to determine the age of groundwater and surface water base flow as a means of assessing flow rates and bulk permeabilities in the aquifers. Comparisons should be made between these values and those already available from borehole tests and if necessary

additional groundwater modelling should be undertaken using the new data (4.2);

10. the results of the Monte Carlo simulations from the groundwater models should be presented as cumulative probability plots (4.2);

11. three-dimensional groundwater models should be run once new information is available on the tailing/cement/water /rock interaction studies. The models should be extended to encompass regional groundwater flow and to identify its contribution to surface waters (4.4);

12. the containment transport groundwater modelling studies should be extended to 10 000 year runs (4.2);

13. the proposals to contain the sediments from the waste rock stockpile should be examined in relation to potential impacts on the aquatic ecosystem (5.3) .

14. environmental impact assessment (including a full ecosystem analysis) should be undertaken assuming a mine life of 40, 50 and 60 years (5.3) ;

15. a comprehensive risk assessment, including ecological, biogeochemical and hydrological factors, at the landscape /catchment scale for both Ranger and Jabiluka should be undertaken in the context of the Jabiluka World Heritage Area (5.4);

16. assurance should be sought that the rehabilitation fund is adequate to meet any long term rehabilitation task should the mine be prematurely closed (5.5);

17. a commitment should be obtained to establish a long term, possibly 100 year, programme to monitor surface water, groundwater and the ecosystem at frequent intervals. This to be subject to periodic review (5.5).

Appendix 1 – Members of the Independent Scientific Panel

Dr Gene E Likens

Director, Institute of Ecosystems Studies
Box AB Millbrook, New York 12545, USA

Professor J A Plant

Assistant Director, British Geological Survey
Keyworth, Nottinghamshire NG12 5GG UK

Dr J C Rodda

President, International Association for Hydrological Sciences
Maclean Building, Institute of Hydrology, Wallingford, Oxfordshire, UK

Professor W B Wilkinson (Panel Leader)

Senior Consultant, Solutions to Environmental Problems (formerly Director, Centre for Ecology and Hydrology), 17-18 Union Street, Ramsbury, Wiltshire SN8 2PR UK