Figure 3b

Energy consumption for US mining and processing per ton of recoverable metal 1955–1987.

Copper

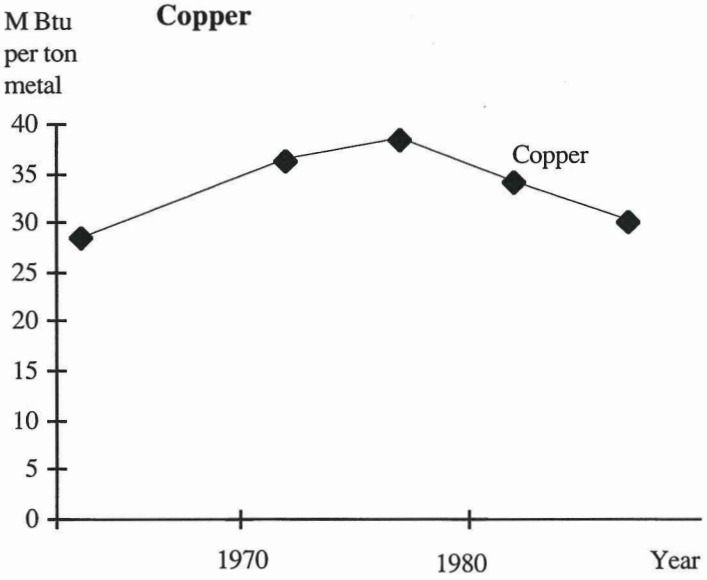


Figure 4

Energy consumption for US primary metal production 1955–1987.

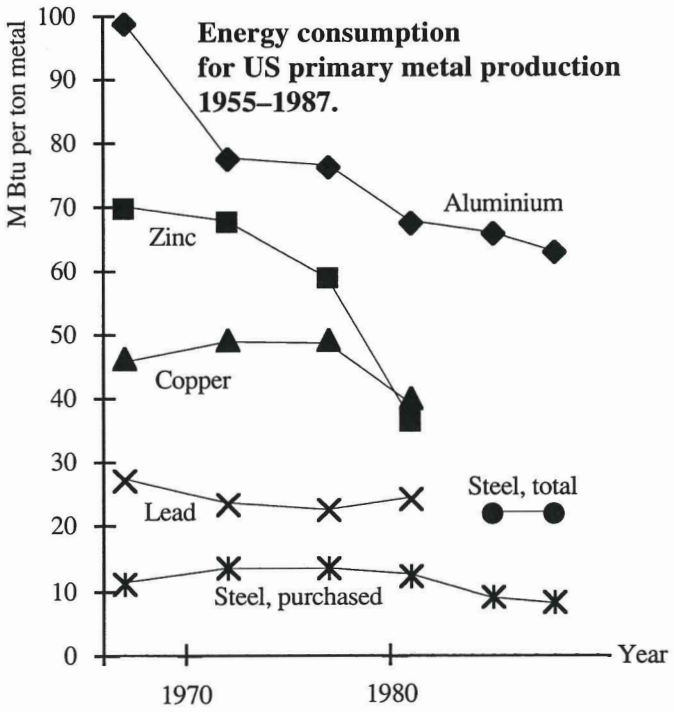
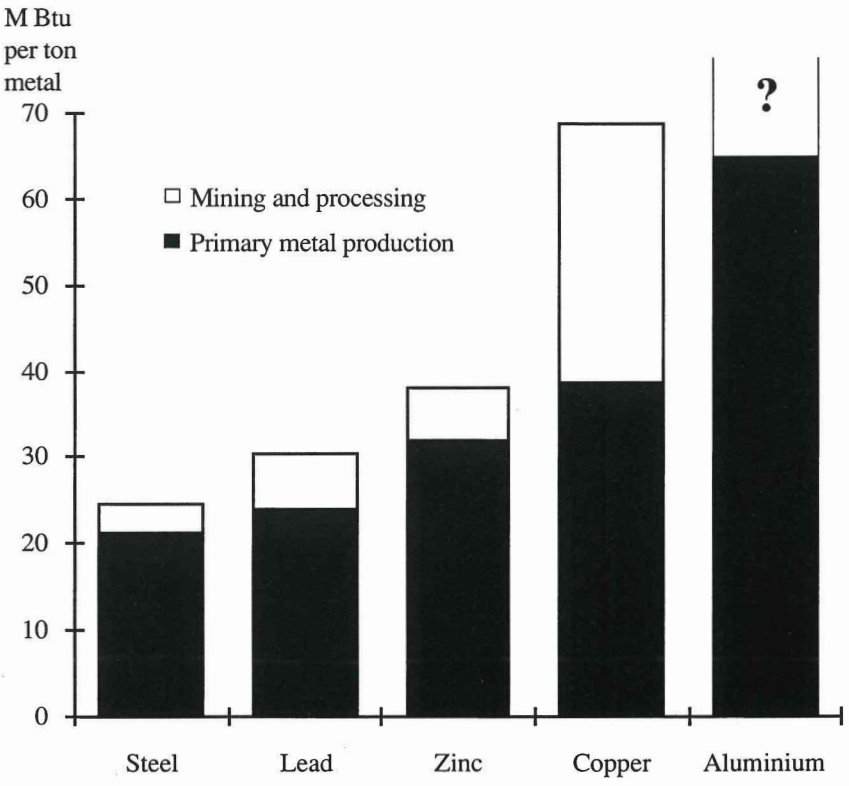


Figure 5

Total energy consumption for US production of selected metals.



Rössing Uranium: The radiation debate and the IAEA

By Greg Dropkin

In 1976 Rio Tinto Zinc began production in the Rössing uranium mine of Namibia. In 1992 the critical "Past Exposure" report was published including an analysis of radiation and other hazards at Rössing. This report caused a major debate. A mission from the International Atomic Energy Agency visited Namibia and Rössing in 1992. The IAEA-report was published in May 1993.
In this article Greg Dropkin of the Namibia Support Committee reviews the IAEA-report.

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INTRODUCTION

The Rössing uranium mine is located in Namibia, which gained political independence in March 1990 after 75 years of South African colonial and military rule.

Rössing is controlled by the British multinational mining company RTZ. The mine was constructed and operated in defiance of the United Nations, and formed a major source of revenue for the South African colonial regime. It supplied uranium internationally, including 7 500 t for the (British) Central Electricity Generating Board. A secret British Nuclear Fuels contract for 1 100 t was approved in 1976 but its existence was persistently denied until 1988 when Lord Hatch finally extracted an admission from 11 civil servants in the Ministry of Defence. Other major customers include EdF (France), and a variety of Japanese power companies.

In 1988 a sanctions campaign based on the company's financial role in the South African occupation provoked a blockade of processed uranium by trade unionists on Liverpool docks. Media coverage and debates in the Japanese Diet (Parliament) led to the non-renewal of various supply contracts.

Production began in 1976, after the era when supposed ignorance of radiation hazards had served as a convenient excuse for corporate negligence in the uranium mining industry. At first, the mine depended heavily on contract labour. Black men would leave their homes in the North and work on 11 month contracts, living in all-male hostels and sleeping on concrete bunks, up to 16 to a room. Many were housed in a camp situated right next to the tailings dam containing radioactive mill wastes. In the early years there was little or no protection from the dust. By 1977, the company began to recognise problems. An internal committee survey of health, safety, and housekeeping (April 1977)[1] scanned various areas, such as the chemical labs:

"...In the sample preparation room, which has a sign on the door stating that workers in this room must wear eye protection, of nine workers seven were without eye protection. Outside was a littered mass of discarded sample bags. Leaning haphazardly against the building were approximately 10 cylinders of gas, with no support racks of chains, all in danger of falling over. The black and coloured eating and locker rooms were a dirty filthy mess of discarded food, paper etc. all covered in flies and never been cleaned for a lengthy period."

When the workers went on strike in the winter of 1978, they appealed:

"...Our bodies are covered with dust and one can hardly recognise us. We are inhaling this uranium dust into our lungs that many of us have already suffered the effect. We are not provided with remedies and there is no hospital to treat us. Our bodies are cracking and sore..."

Rio Tinto Zinc grew concerned about international publicity and the possibility that Namibia would soon gain independence under the 1978 UN plan. They began significant improvements in housing, health and safety. Medical facilities were now to be provided for all employees. By 1982, radiation dose levels were clearly falling.

But the very dangerous period from 1976 to 1982 is bound to have medical consequences, some of which will only show up during the 1990s or later because of the long delay between exposure and cancer. Many of the workers from the early days left the mine long ago.

In 1989, with independence near, the Mineworkers Union of Namibia (MUN) appealed for information on radiation and other hazards at Rössing. Workers remained concerned about conditions, e.g. in the final processing areas.

"Here there are only black workers. Many work 8 hours a day for a continuous period of 7 days. We are never out of the dusty area – even our lunch facility faces the product recovery area. At one time we were told to work inside the dust collector. We wore protective equipment. After an exposure of 8 hours we showered and changed. I cleaned my nose and throat and found I had uranium dust blocking my

nose. I showed this to the general manager, but he said it was not uranium dust. The company did not want to pay the safety allowance and so would not admit that we may have been contaminated with uranium dust. Many of us in product recovery experience feelings of drowsiness and lethargy. When this is reported workers are transferred to another area..."[2]

The union also suggested a scheme of safety representatives with full access to information. The company refused to consider the proposal, and replied in the pages of "The Namibian" newspaper[3]:

"No employee has ever approached the maximum radiation limit... and because Rössing applies the best possible health and safety standards, no health problems are anticipated in the future..."

Equally, in the "South African Medical Journal"[4] senior medical staff claimed:

"The standards set by the International Commission on Radiological Protection (ICRP) are easily met. No evidence has been found from direct measurements or from modelling to suggest that employees and/or the general public have been exposed to radiation levels above, or even close to, the minimum limits recommended by the ICRP."

It sounded good, but it was not true.

"Past Exposure"

In 1992, the Namibia Support Committee (a UK solidarity organisation) and Partizans (an international network of groups affected by RTZ mining operations) published an independent analysis of radiation and other hazards at Rössing called "Past Exposure", which drew on a file of internal company documents, obtained by the Namibia Support Committee during the colonial period. These reveal major flaws in Rössing's approach to radiation control during the early 1980's, even by the standards of the ICRP at that time.

The company failed to monitor the "Whole body Dose". Procedures for analysing uranium in urine were a shambles. Workers encountered very high levels of uranium dust in the yellowcake drying and packaging area (final product recovery), and very high dose rates of external (beta/gamma) radiation in this department during 1981/2. High cumulative whole body doses and corresponding cancer risks for workers in final product recovery are implied by the data. The documents hint at even higher doses during the 1977–80 period, before the company made a serious effort to clean up this operation. Uncontrolled liquid seepage from the tailings dam before 1981 amounted to an estimated 780 million gallons over a 12 month period. No matter how safe current practices may appear, the damage has been done and will persist.

When "The Namibian"[5] summarised "Past Exposure" in March 1992 Rössing lost their characteristic composure, perhaps because the company was busy negotiating a new contract with Kyushu Electric Power Company. Their in-house magazine[6] alleged "this false and malicious attack seems to be calculated to damage the Company's reputation and thereby its chances of finding new business. Those responsible should bear in mind the possible consequences for Namibia in terms of jobs, foreign earnings and the payment of taxes..." Their manager for Corporate Affairs Clive Algar told "The Namibian"[7] he reckoned the book was a "mixture of distortions and half-truths cunningly woven together into a plausible text" whilst admitting that he had not actually read it yet. Then the company threatened to sue the newspaper and received an unedited right of reply, purporting to answer the technical arguments while evading all of them.[8]

A few basic points stood out immediately.

- If there were no problems at Rössing, why had the company not negotiated an Environmental Health and Safety Agreement with the Mineworkers Union of Namibia? At Rio Algom, an RTZ-controlled uranium mine in Canada, the agreement reached in 1981 established a team of Health and Safety Inspectors and Environmental Monitors paid by the company but accountable to the union which appoints and can dismiss them. These Inspectors and Monitors take action based on access to all company data on workers' health and environmental matters.
- If current standards at Rössing were excellent and the past practices were also fine, why not open the books? Let the MUN and scientists of its choice have access to all environmental data, dose records, medical records etc back to 1976, so that a full independent analysis could proceed.
- "Past Exposure" is an account of the years up to 1985. The company could not dismiss allegations about the past by praising their own current practices.
- "Past Exposure" is based on detailed evidence from internal company reports.

Blasting in the open pit at Rössing.

Rössing could not refute the allegations without referring to the contents of these reports.

IAEA

Soon after the debate began, the International Atomic Energy Agency sent a mission to Rössing in September 1992 at the invitation of the Government. As the UN agency responsible for radiation protection, the IAEA was a natural choice for Namibia given the lack of independent technical expertise in the new nation and the history of UN involvement. But its intervention has not calmed the waters.

The IAEA report, originally due in January, only surfaced in May 1993. But before the mission departed, some glowing "Preliminary Findings" were incorporated in a press statement by the Namibian Ministry of Foreign Affairs on 11 September 92 and later cited in a UK parliamentary answer. The union, however, accused the IAEA team of relying solely on company information while excluding the workers' experience. A group of 24 scientists, activists and researchers attending the World Uranium Hearings in Salzburg wrote to the IAEA mission leader on 18 September 1992 with a host of technical questions.

Rössing and the MUN traded full page adverts in the Namibian press. The company proclaimed "All those who have the interests of Namibia at heart should now give encouragement to Rössing in its drive to increase its uranium sales, thus enabling it to return to its preeminent position in the Namibian economy." The union stressed the IAEA's failure to investigate medical separation and permanent disability cases (over 200 in all) and concluded "Namibians cannot be fooled anymore!"

In January 1993, the union tabled a comprehensive Environmental Health and Safety Agreement, drawing on international experience. Six months later, there had been no negotiation on the substance of this proposal. The union also began to consider possible epidemiological studies of the workforce, past and present. These ideas could help workers. The IAEA report had a different purpose.

The 231 page report, given to selected journalists and interested parties in the UK, is naturally seen by the company as an authoritative reply to its many critics. On 5th May, RTZ gave copies of the IAEA's "Executive Summary" to shareholders and the press. The Head of Public Affairs also wrote to me:

"I believe you will find that it does contradict the claims you have made in 'Past Exposure' and I trust therefore that coming from this source you will accept the findings."

The report neither contradicts the evidence of "Past Exposure" nor speaks to the problems arising from workers' experience or the questions put to the mission by the Mineworkers Union of Namibia on their arrival. The chorus of praise in the IAEA's "Preliminary Findings" and "General Conclusions" simply fades away when examined. The full report is both revealing and highly self-contradictory.

General conclusions

1) The IAEA found "reliable records for all radiation doses received by individual radiation workers are available only from 1980–81 on to the present" and "Results of urine analysis for the years 1976 to 1978 are not available". But they ignored company reports showing monitoring of uranium in urine samples by the South African Institute for Medical Research had been grossly unreliable. All urine data prior to 1986 is therefore suspect but the IAEA presents this data as accurate.

2) The IAEA confirm published 1982 data on high levels of beta/gamma radia-

tion in final product recovery. The report reveals problems with contaminated seepage from the tailings dam and dust control – past and present. No environmental radiation monitoring data before 1980 is shown.

3) The IAEA discovered that 16 years after starting production, Rössing had still not completed a plan for the decommissioning and long term stabilisation of the tailings. The company may claim to be committed to the best available practice, but US legislation adopted in 1978 requires such plans to be formulated, discussed in public and revised in response to criticism before obtaining approval. Likewise the various Environmental Impact Statements prepared for Rössing in 1991 and 1992 remain unpublished, in contrast with legal requirements in the US and elsewhere.

4) One of the aims of the IAEA ("To corroborate the results of radiation monitoring...") was badly formulated and therefore unachievable. The method chosen to pursue it was flawed in principle. The IAEA measured some high radiation levels, but omitted them from their "Executive Summary".

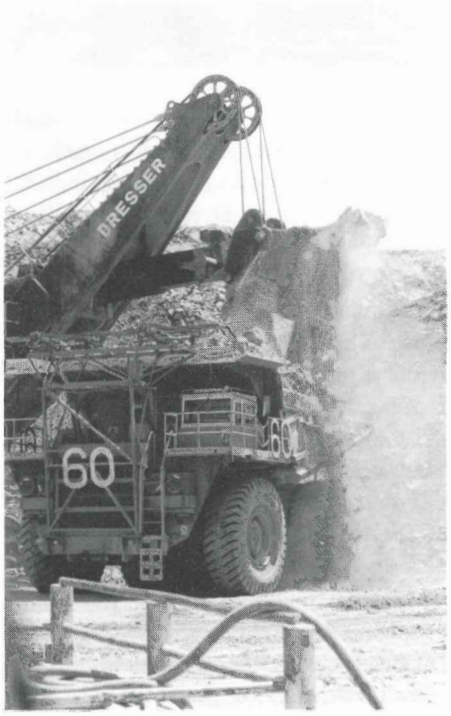
5) Despite another stated aim, the mission did not "make an assessment of the long-term health effects resulting from exposure to radiation". The Executive Summary "General conclusions" asserts that "Grievances exist about some cases of illnesses, including lung cancer, which are thought to be related to occupational radiation exposure. However, such cases can only be addressed in comparison to national vital statistics, which do not seem to exist in Namibia at the present time." In fact, the failure of the former colonial regime to compile vital statistics does not rule out all conclusions. Cases can be evaluated in relation to regional, continental, or international statistics pending the determination of Namibian incidence rates. Comparitive studies and cytogenetic determination of the absorbed radiation dose are already possible.

6) The IAEA were given access by Rössing to any document they requested but the full report does not cite any of the company documents analysed in "Past Exposure" or comment on the decision to omit this evidence. Parts of the full report are contradicted by evidence which had been drawn to the attention of the mission by the MUN. Did the IAEA request these documents and if not, why not? Some attempts to reply to questions from the union are evasive.

7) The IAEA failed to detect Rössing's history of inappropriate standards for uranium dust, as shown by company documents mentioned by the MUN but ignored by the IAEA, or alternatively by data presented by Rössing in 1992 and used in the full report. Despite this cited evidence, the Executive Summary claims that the Rössing Codes of Practice were always "consistent with the recommendations of the International Commission on Radiological Protection that were available at the time" while the full report claims the Rössing uranium dust standards were "essentially the same as those recommended by the ICRP".

8) The Executive Summary is contradicted by the full report. The report was apparently not edited/reviewed centrally, and lacks any comment on contradictions between different parts.

I will support these conclusions by analysing some stated aims and actual achievements of the mission.



Loading haultruck in Rössing open pit.

GOALS

The first question to ask of the IAEA report is: What did it aim to achieve, and did it succeed? The four stated aims of the mission cover radiation monitoring, tailings management, occupational safety and long-term health effects. Before considering these, I wondered whether the IAEA set out to evaluate the evidence in "Past Exposure"?

Examining relevant evidence?

Rössing's past record on dust, uranium toxicity, radiation and tailings, is found in the company's own documents. In May 1992, shareholders invited the RTZ Chairman Sir Derek Birkin to deny the authenticity of these documents. He declined. Likewise, the "New Scientist" magazine[9] commented "...the company does not dispute the parts of the report which quote internal documents."

The IAEA mission could have asked Rössing to supply all the company documentation quoted in "Past Exposure", as the union requested.[10] A key document mentioned by the MUN[11] was the December 1982 "Rössing Radiation Report" by their Chief Environmentalist.

Aside from reproducing the MUN proposals, the IAEA report does not refer to any of the company documents quoted in "Past Exposure". Why not? According to the IAEA[12] "Any information, any document and any material that were requested by the mission members were provided by the staff of Rössing." Did the IAEA not ask for the December 1982 "Rössing Radiation Report"?

Some of the data quoted by the IAEA confirms problems highlighted in "Past Exposure". External radiation rates in the final product recovery area[13] are shown as 27 microSieverts per hour in 1980, in excess

of the ICRP guidelines at that time (25 microSieverts per hour). No data is given for earlier years in the final product recovery area or anywhere else, despite the fact that "the 1979 monthly reports contain graphs indicating average radiation exposures in various areas of mine operations dating back to and including most of 1977".[14] But the corresponding final product recovery external radiation level for 1982 (17.5 microSieverts per hour) is virtually identical with the 1982 annual average as derived from the December 1982 "Rössing Radiation Report". The 1981 figure of microSieverts per hour[15] is much lower than the 1981 annual average of 22 microSieverts per hour derived from the December 1982 report.[16]

The IAEA did not set out to examine the claims of "Past Exposure" but they did support some of them.

Corroborating radiation monitoring

The first stated aim of the mission was "to corroborate the results of radiation monitoring so far carried out by Rössing by making independent measurements together with the specialists from Rössing". Sadly, this aim is not achieveable. Independent measurements taken in 1992 and compared with parallel measurements by Rössing could not corroborate "the results of radiation monitoring so far carried out by Rössing". That would require evidence on how monitoring procedures had evolved and what methods of quality control and quality assurance were implemented in the past.

The IAEA does not seem to understand this. They report[17] that the leader of the mission J U Ahmed "clearly explained" the reliability of the Rössing results to the union. After claiming that environmental gamma radiation levels would be the same in 1992 as in 1976 because "the ore body at Rössing is fairly uniform in its distribution of uranium" the IAEA asserted: "Therefore the results of measurements made by the mission, which were equal to those measured by the Rössing group, established the reliability of Rössing results. The same was true with those of radon and dusts. Therefore, there should be no problem using Rössing data for making the assessment of health effects from radiation exposure." This argument is implausible even for gamma levels in the open pit, where the IAEA readings never exceeded 2.5 microSieverts/hour while the 1982 "Rössing Radiation Report" refers to contact readings varying from 2 to 200 microSieverts/hour with an exceptional contact reading of 600 microSieverts/hour at bench 11 in 1980, and readings at 1 metre distance varying from 0.9 to 12 microSieverts/hour.[18] In the crushers or mill the argument is absurd – the IAEA reported[19] steep changes in average beta/gamma levels encountered in final product recovery and average respirable dust levels in the crushers. Any inference that because the Rössing data for September 1992 is reliable therefore the data for May 1976 – August 1992 is reliable, depends on the assumption that Rössing's monitoring techniques and levels of technical competence and quality control are unchanged since 1976.

The mission leader's confidence in using Rössing data to assess health effects is further contradicted by the evidence contained in the full report on dust doses and monitoring of uranium in urine and by evidence which the IAEA disregarded.

Dust dose

The IAEA noted[20] that "reliable records for all radiation doses received by individual radiation workers are available only from 1980–81 on to the present". Rössing had reconstructed dose records for the earlier years by "backward extrapolation" and was now (1992) in the process of trying to improve these estimates by "consideration of the graphs for average monthly exposures in different areas dating back to early 1977".[21]

The IAEA comments "This particular extrapolation appears to be very reasonable for exposure to external gamma radiation and to inhalation of radon progeny ... but exposures to ore dust may be more uncertain since these are highly dependent on protective measures to minimize exposure to ore dust." In other words, even if the environmental level of ore dust was known reliably (which depends on the accuracy of the monitoring technique at all times in the past), the actual exposure depends on the effectiveness in practice of the respiratory protection and other methods employed to shield workers. This depends, for example, on whether respirators were always provided, always worn, always fit properly and always worked to specifications.

While the leader of the mission claims "there should be no problem using Rössing data for making the assessment of health effects from radiation exposure", Part 3 shows that the data isn't all available or reliable and reconstructing exposures to ore dust "may be more uncertain". I return to this issue later.

Urine samples

Urine samples are taken monthly from selected workers, and monitored for uranium content. It seems the IAEA did not make any quality control measurements of current urine sampling technique including the sample analysis in South Africa, but suppose they had done and deemed the current results to be 100 per cent reliable. What would this reveal about the past reliability of urine sampling? The technical letter from scientists to Ahmed[22] asked: "What methods of quality control and quality assurance are and have been applied to the monitoring of uranium in urine?"

Reading the full report[23] we learn that "results of urine analysis for the years 1976 to 1978 are not available". This important discovery is omitted from the Executive Summary[24] and the General Conclusions[25] where instead we read:

"Occupational and environmental radiological surveillance programme at Rössing is comprehensive and is of high standards. This surveillance programme is efficiently carried out by well qualified technical staff which maintains an excellent library" ... "A comparison of Rössing radiometric techniques and results with those used by

mission experts indicates that results of the Rössing programme for monitoring radiation and radioactive contamination can be considered reliable and within internationally accepted guidelines for accuracy."

As noted the union asked the IAEA to obtain particular company documents. Had they done so, or even taken the evidence into account after reading "Past Exposure", they would know that in 1984 the Chief Environmentalist wrote a "Urinalysis Quality Control" report[26] uncovering gross defects in the analytical technique of the South African Institute for Medical Research.

The problems were not resolved by 1986, as the Assistant Supt. Environmental Control reported in his "Quality Control of Urinalysis". The IAEA never mentions this issue but presents the same company data[27] criticised in "Past Exposure" and discusses it[28] without comment on the reliability of this data for 1979–1986.

Tailings

The mission's second aim was "To carry out an assessment of the planned programme for the management of uranium mill tailings, including decommissioning and rehabilitation of the tailings pile". The IAEA expert read "A conceptual decommissioning plan for the Rössing uranium mine, Namibia, Vols I–II", prepared as a draft in June 1992 (midway between the publication of "Past Exposure" and the arrival of the IAEA mission) by engineering consultants Steffen, Robertson & Kirsten. After making a few favourable general remarks he decided that "making comments on the draft decommissioning plan is inappropriate at this time, as many important technical details are still to be finalised". The Executive Summary omits any further reference to decommissioning but declares[29] "the Rössing management of mill tailings and related aspects are adequate to the state-of-the-art" and adds a General Conclusion:[30]

"The mill tailings management programme of Rössing, and the associated surveillance programme are of good standard and conform with the current international standards".

Of the four aims, the first was badly formulated and the second could only be completed by analysing a draft plan which the IAEA decided not to comment on at this time. But what did the mission discover?

RADIATION MONITORING

The Executive Summary[31] notes the results obtained in the radiation monitoring exercises carried out by their expert J Viljoen in parallel with Rössing and presented more fully in Part 2. While the parallel measurements of external radiation rates were indeed comparable, no Rössing data on radon or dust is shown alongside IAEA figures. The Executive Summary then selected the favourable data from Part 2. The less favourable results are either omitted or presented in more general terms, without the data. Here are just two examples.

Reclaim tunnel no. 4

The Executive Summary skips Reclaim tunnel no. 4.[32] In Part 2, J Viljoen discusses Reclaim tunnel no. 4 extensively.[33] On 7 September, the expert noted the area to be partially clean and that "ventilation appeared erratic."[34] He found radon gas at 16 270 Becquerels per cubic metre, corresponding to a Working Level of 0.94. The ICRP guideline maximum Working Level is 0.4. Returning on 8 September, Viljoen found a clean-up in progress and noted "air movement was still erratic, but had improved since the previous shift. Reverse air flows were still noticed under the conveyor... It may be necessary to place a fan in this area to improve air quality when people have to work there."[35] Viljoen recommended[36] that the Government inform Rössing that "conditions in the reclaim tunnel no. 4 require further improvement..."

Having deleted any mention of Reclaim tunnel no. 4 from the Executive Summary, it was then possible to reach a "General Conclusions"[37] that "Radiation exposure levels at various facilities are very low, much lower than the current international limits."

Final product recovery

In the final product recovery area, Viljoen found[38] a gamma dose rate of 4.5 microSieverts/hour in the centre isle of the drum filter area with a gamma-beta rate of 1 800 "counts per minute". Although Viljoen nowhere states how "counts per minute" might be converted into microSieverts/hour – which depends on the monitor calibration and efficiency as well as the energies of the radiation encountered – the rate is around 25 times higher than the background levels measured in Arandis.[39] At the no. 2 filter he measured 2 300 counts per minute (over 30 times background). In the 3 ton bin area[40] he found 5 000 counts per minute (over 70 times background). At the end of the second screw conveyor,[41] the gamma-beta rate is given explicitly as 40 microSieverts/hour with a gamma dose of 7 microSieverts/hour. This rate is extremely high: exposure for 10 hours per week would produce an annual dose of 20 milliSieverts, the current ICRP guideline, without any additional internal dose from radon or dust. On the steel beam at the drum exit, Viljoen noted[42] an exceptional level of uranium dust.

The Executive Summary does not give any figures from the final product recovery area, but states:[43] "Some contamination was noted on the screen in the decontamination area, but not considered significant. Some higher contamination was noted in the 3 t bin area, below the valves and cooling water tanks, but only localized in a very small area".

The ILO expert B Allan went even further, declaring[44] that in the final product recovery area "Readings by J Viljoen showed no high readings".

By now it should be clear that the Executive Summary is not an accurate reflection of the full report, and the "General Conclusions" were distilled to put an even better gloss on the Executive Summary. I will

now discuss some of the problems and contradictions in the IAEA analysis of long term health effects and their new information on tailings hazards.

HEALTH EFFECTS

The context for the IAEA mission was a debate about the future health impacts of past exposures to radiation and dust. Part 3 (Assessment of the long-term health effects due to occupational radiation exposures) intervenes in that debate. It was prepared by David K Myers, an IAEA expert from Canada.

Dr Myers declares[45] that along with the MUN proposals, "Past Exposure" reveals "serious weaknesses in the understanding of the long-term health effects of exposure to low doses of ionizing radiation".

Surprisingly, given his long experience in the field, Dr Myers misunderstands several MUN questions, contradicts the view of the IAEA tailings expert, fails to comment on spectacular flaws in the evidence presented to him by Rössing, and asserts that a "reliable scientific study" of occupational health impacts "is not possible at present in Namibia".

Also, he never refers to any of the company documents requested by the MUN[46] such as the December 1982 "Rössing Radiation Report".

Whole body dose

The ICRP system is based on controlling the 'whole body dose' combining all external and internal doses. Dr Myers discovered[47] that "reliable records for all radiation doses received by individual radiation workers are available only from 1980–81 on to the present" and that "results of urine analysis for the years 1976 to 1978 are not available".[48]

He does not mention the grossly inaccurate urine analysis discussed above, or the request from the MUN[49] for cytogenetic assessment of whole body doses.

In December 1982, the Chief Environmentalist wrote[50]:

"To refine our control programme and to bring it in line with the International Commission on Radiation Protection (ICRP) recommendations, we now require to determine:

1. The organs at risk from various types of radiation and the degree to which past and present employees have accumulated such radiation burdens.

2. To use this information to calculate the ICRP whole body doses on a routine basis. Currently only the external dose is considered at Rössing."

The Chief Environmentalist then called for investigations including "determination of lung irradiation burdens due to accumulation of unsoluble uranium and its daughter isotopes."

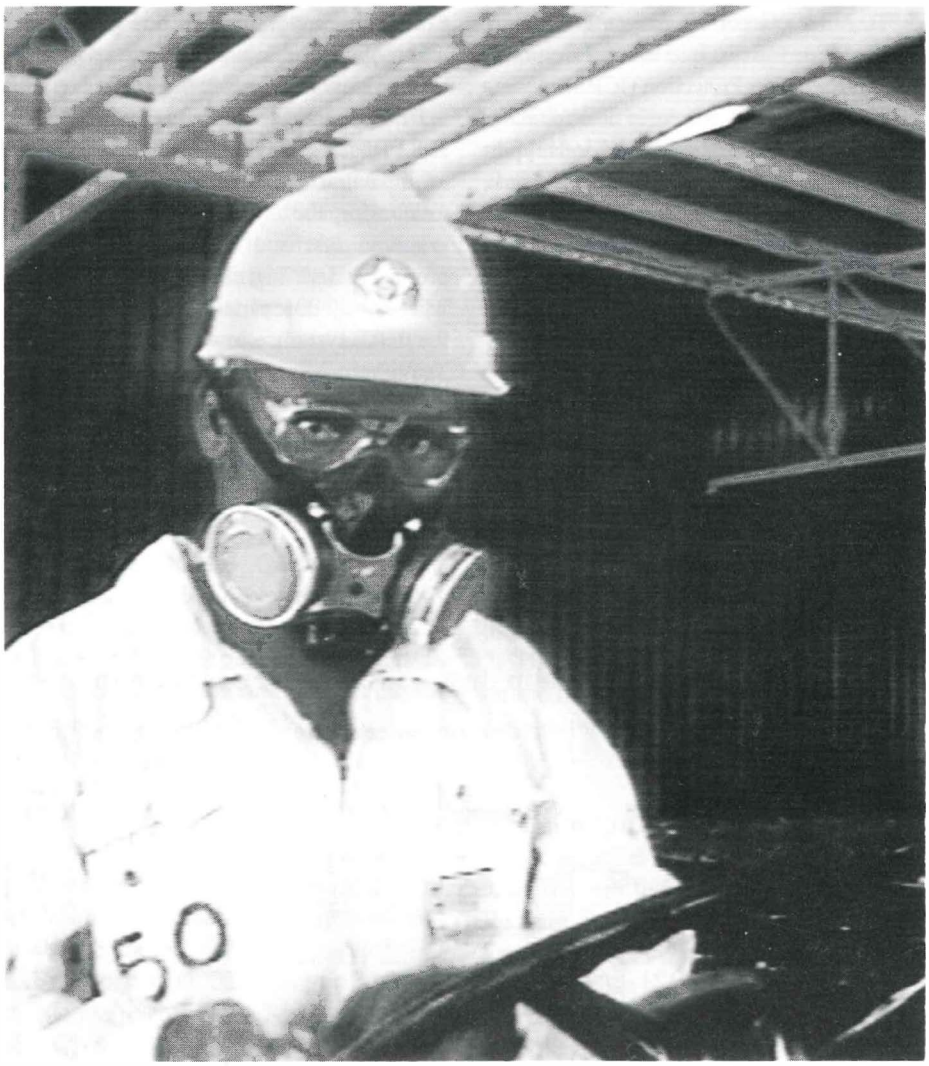
This evidence means that in December 1982 Rössing was told by its Chief Environmentalist that the company was not monitoring the alpha doses from inhaled uranium dust and its radioactive decay products, and had to begin calculating whole body doses in order to comply with the ICRP system.

Without commenting on this the IAEA could not possibly claim to refute "Past Exposure", whatever RTZ may believe.

Table 1
ICRP and Rössing radiation and dust limits.

Year	Total alpha in dust				Uranium in dust	
	Uranium in ore		Uranium concentrate		Radiological limit mg/m³	
	Rössing	ICRP	Rössing	ICRP	Rössing	ICRP
1976	– pCi/m³	– pCi/m³	– pCi/m³	– pCi/m³	0.003	0.003
1977	60	60	5	5	0.003	0.003
1978	60	60	5	5	0.03	0.03
1979	60	0.71 Bq/m³	5	0.63 Bq/m³	0.03	0.03
1980	60	0.71	5	0.63	0.03	0.03
1981	60	0.71	5	0.63	0.03	0.03
1982	0.71 Bq/m³	0.71	0.63 Bq/m³	0.63	0.03	0.03
1983	0.71	0.71	0.63	0.63	0.03	0.03
1984	0.71	0.71	0.63	0.63	0.03	0.03
1985	0.71	0.71	0.63	0.63	0.03	0.03
1986	0.71	0.71	0.63	0.63	0.03	0.03
1987	0.71	0.71	0.63	0.63	0.03	0.03
1988	0.71	0.71	0.63	0.63	0.03	0.03
1989	0.71	0.71	0.63	0.63	0.03	0.03
1990	0.71	0.71	0.63	0.63	0.03	0.01
1991	0.71	0.71	0.63	0.63	0.03	0.01
1992	0.30	0.30	0.30	0.30	0.01	0.01

Note: Data supplied to the IAEA by Rössing. From tables 1 and 2, Part 3, pp 46–47. pCi/m³=picoCuries per cubic metre; Bq/m³=Becquerels per cubic metre; mg/m³=milligrammes (of uranium) per cubic metre; U Con=Uranium concentrate.



Worker driving a fork lift truck in the uranium drum storage area at Rössing.

Currently, "in vivo counting of uranium is used to assess the lung burden from the insoluble compounds" on an ad-hoc basis for final product recovery workers[51] but there is no clue when this began and no data is shown.

I doubt that the company has reliable records of the "dust dose" for 1982, in view of the Chief Environmentalist's comments. We are told[52] that Rössing included the dust dose "in their dosimetry records for a considerable number of years prior to 1992" and there is reference[53] to a 1988 research report by G P de Beer and A H Leuschner of the Atomic Energy Corporation of South Africa advising Rössing on correction factors to apply in calculating the dust dose. We also learn[54] that "an option for the period 1988–92 dosimetry file exists in which protection factors for respirators worn by workers are introduced". But the only specific data shows[55] the 1992 dust dose with a "respiratory protection factor taken into consideration". It would have been useful to see the dust doses from 1982 onwards, if they exist, but at least Dr Myers acknowledged serious problems for 1976–80/81.

Epidemiology

Dr. Myers mentions[56] that "medical files are kept for about 6 000 past employees plus 1 300 current employees". We don't know whether he inspected company statistics for incidence of silicosis, chronic obstructive lung disease, kidney damage, or various cancers within the current and previous workforce. But he does say[57] that the Rössing Chief Medical Officer is negotiating with "cancer treatment centres in Windhoek to see if it would be possible to obtain some preliminary data on cancer frequency among previous employees..." As to the union's concern[58] that "some past employees may die after leaving the Rössing mine from diseases that have been caused by occupational exposures" Dr Myers replies:[59] "Unfortunately a reliable scientific study to investigate this possibility is not possible at present in Namibia, due to the absence of a comprehensive vital statistics record" and he therefore urges the government to establish such a record.

National statistics on births, deaths, and cancer incidence would be an important step forward in Namibia. Dr Myers seems to believe that until then, no conclusions whatsoever can be drawn from any data which may emerge on the incidence of diseases with a possible occupational link. But surely, pending national statistics, such data should be evaluated in terms of regional, continental or international incidence rates. Health comparisons of workers with varying exposures are also possible at this stage, as are cytogenetic studies.

Dr Myers also states[60] that various cancer cases identified by the MUN had cumulative whole body doses ranging from 0 to 44.7 milliSieverts according to their dose records and so it was "extremely improbable that any of these cancers could have been attributable to their occupational radiation exposures..." Were these the same dose records based on "backward extrapolation" although "exposures to ore dust may be more uncertain", without any urine samples in 1976–78 as we were told?

Dr. Myers cites[61] various studies as evidence that doses up to 200 milliSieverts (Japan) or annual rates of 2 milliSieverts (China) or occupational doses averaging 20 milliSieverts per year (Chalk River, Canada) will not result in any significant increase in cancer deaths. He doesn't men-

tion the recent long-term follow up of 8 000 workers[62] which found highly significant associations between very low doses of external radiation and increases in the cancer death rate 20 years later. An exposure to 10 milliSieverts was associated with a 4.94 per cent increase in cancer mortality with 20 year delay.

Since the impact of exposure in the 1976–1982 period is likely to be felt from 1996 onwards, it is notable that Dr Myers concludes[63] that "the evidence on fatal injuries, lost-time accidents and radiation exposure of workers all indicated that the Rössing Uranium Mine is currently a safe place to work..." and the management "deserves a compliment for these improvements". What does that mean about the past and its effect on future health prospects?

Uranium dust standard

By contrast, Dr Myers does discuss the uranium dust limit adopted by Rössing. The union asked[64] the IAEA to comment on: "The airborne uranium dust standard of 0.15 mgU/m^3 which is the only standard for airborne uranium cited in either the 1982 Rössing Radiation Report or the July 1985 Environmental Control Report. This standard was six times weaker than the relevant ICRP limit at that time for dust containing uranium oxide in the Final Product Area..."

Dr Myers claims[65] the MUN (and by implication "Past Exposure") had confused the standard for protection against chemical damage to the kidney with the radiation control standard. Rössing originally made this claim in "The Namibian"[66] and their Manager for Corporate Affairs Clive Algar repeated it.[67] I replied[68] long before the IAEA Report was completed, and Clive Algar never responded. Dr Myers cannot be expected to read the Namibian press. But he appears to have missed that "Past Exposure" discussed the uranium toxicity limit[69] and the ICRP radiation control standard[70] and also reproduced part of the December 1982 Radiation Report[71] showing the uranium limit at Rössing.

Who cares whether Rössing adopted the ICRP standard? Obviously the company is very concerned to establish such a claim in public and it is therefore worth knowing that by their own account, it is untrue (see below). The ICRP inhalation standards were designed to ensure that workers remained within the ICRP annual dose limit. But the dose limit never guaranteed safety. Based on risk estimates which were later revised, it involved a judgement (by the ICRP) of acceptable levels of risk for workers.

Dr Myers[72] does not mention the company documents from 1982 and 1985 cited by the MUN. Instead, he refers to a table prepared for the IAEA by B Isaack who is listed[73] as Senior Environmentalist "since 1990".

According to this table[74], Rössing has always had two standards for uranium in dust, one for radiological protection and one for chemical toxicity. The chemical toxicity limit was always 0.15 mg/m^3. The Rössing radiological standard for 1978 – 1991 is listed as 0.03 mg/m^3.

The first puzzle is this: if the radiological standard for uranium in dust was 0.03 mg/m^3 in 1982 and had been for several years, why did the Chief Environmentalist in his December 1982 Radiation report list only one standard for airborne uranium, namely 0.15 mg/m^3, and never mention a radiological standard of 0.03 mg/m^3? Likewise the October 1982 "Safety and Environmental Control at Rössing" report mentions only one standard for uranium natural in dust, namely 0.15 mg/m^3. And the July 1985 "Environmental Control" report by the Ass Supt. Environmental Control mentions only one standard for uranium natural (in dust), namely 0.15 mg/m^3.

In other words, the Rössing documents ignored by the IAEA directly contradict the claim that the company had adopted the appropriate radiological standard for airborne uranium in 1982 and 1985.

I do not know why the IAEA failed to evaluate the evidence in "Past Exposure" or the December 1982 "Rössing Radiation Report" which, as J U Ahmed told us[75], would have been supplied to the mission on request. Strangely, the experts also failed to spot any errors in the Tables prepared for them by Rössing and the various Codes of Practice, which together constitute the alternative evidence considered in Part 3.

Dr Myers tells us[76] that the 1977 Rössing Code of Practice required "inhalation of uranium dust shall be less than 2.5 milligram per day". The table supplied by Rössing[77] shows a 1977 company radiological limit for uranium dust of 0.003 mg/m^3. These two statements are in conflict. The ICRP reference man assumption of 1.2 m^3/hour intake (light work) or twice that for heavy work means that in an 8 hour day, an average worker would inhale between 10 and 20 cubic metres of air. To reach 2.5 mg would mean inhaling over 800 cubic metres of air per day at the supposed radiological limit of 0.003 mg/m^3. Not even the Namibian miners work that hard! But the Code of Practice would fit with a dust limit of 0.15 mg/m^3 corresponding to a daily limit of 1.5 mg light work or 3 mg heavy work.

There are many other curiosities in the story of the uranium dust standard as told to the IAEA by Rössing.

According to Table 1, the Rössing total alpha limits for uranium in ore and uranium concentrate both changed after 1991 as did the ICRP total alpha limits. According to Table 2, the Rössing radiological standard for uranium in dust also changed after 1991, however the ICRP radiological standard for uranium in dust is said to have changed after 1989. Since the "radiological limit" is derived from the total alpha limit, this is odd.

In 1979, according to Table 1 the ICRP standards for "Total alpha in Dust" became 0.71 Bq/m^3 for uranium in ore, and 0.63 Bq/m3 for uranium concentrate. These figures are derived from ICRP 30 and are consistent with the South African standards.[78] But Rössing only adopted these limits in 1982 according to Table 1. The Rössing limit for uranium concentrate before 1982 is said to have been 5 pCi/m^3 = 0.185 Bq/m^3 (since 100 pCi = 3.7 Bq) i.e. stricter

than the appropriate ICRP limit. But the limit for uranium in ore before 1982 is said to have been 60 pCi/m^3 = 2.2 Bq/m^3, over 3 times weaker than the ICRP limit. By their own account, Rössing standards were seriously out of compliance with the ICRP standards for "total alpha in dust" (uranium in ore) in 1979, 1980, and 1981 according to Table 1.

In the period 1982 – 1989 all the Rössing and ICRP standards apparently agreed with each other, according to Tables 1 and 2. Unfortunately, the claimed values for the ICRP Radiological standard for uranium in dust are wrong. The claimed ICRP standard of 0.03 mg/m^3 is not far from the ICRP dust limit for uranium Con (0.025 mg/m^3 during 1979–1991) but is three times the ICRP limit for uranium in ore (0.01 mg/m3 in 1979–1991). ICRP 47, part of the guidance for the IAEA, discusses the ore dust limit.[79]

For uranium concentrate, the only nuclides are Uranium 238, Uranium 234, and Uranium 235. 1 milligramme of uranium (natural) has an activity of about 25 Bq (almost all from Uranium 238 and Uranium 234 which are in equilibrium, each contributing about 12.5 Bq) and therefore the ICRP limit of 0.63 Bq/m^3 corresponds to a uranium dust limit of 0.63/25 = 0.025 mgU/m^3.

For uranium in ore, the Uranium 235 series again contributes a very small fraction and the Uranium 238 series is in equilibrium. But now there are five long-lived alpha emitters which must be considered: Uranium 238, Uranium 234, Thorium 230, Radium 226, and Polonium. This time, 1 milligramme of uranium (natural) corresponds to a total long-lived alpha activity of 5 x 12.5 = 62.5 Bq, ignoring the ^{235}U series. Therefore the ICRP limit of 0.71 Bq/m3 corresponds to a uranium dust limit of 0.71/62.5 = 0.011 mgU/m^3. Note the figure of 0.71 Bq/m^3 corresponds to an Annual Limit of Intake (ALI) of 1 700 Bq (using the Reference Man assumption of 2 000 hours/year and 1.2 m^3/hour) and that this ALI is derived from the long-lived alpha emitters[80].

By now it should be clear that Table 2 is based on a misunderstanding of the ICRP radiological dust limits, at the very least.

Even in 1992, an alpha activity limit of 0.30 Bq/m^3 as stated in Table 1 corresponds to an ore dust radiological limit of 0.005 mg/m^3, not 0.01 mg/m^3 as stated in Table 2. Dr Myers doesn't comment. How much longer do the miners have to wait for Rössing to adopt the ICRP limits?

Ten years after the critical period in Rössing's history was ending, the company was still confused. The data for 1982 and 1985 is directly contradicted by the company documents cited by the union which show one and only one limit for airborne uranium dust, namely 0.15 mg/m^3. But if that documentary evidence is ignored and Tables 1 and 2 are to be believed, Rössing was out of compliance with the ICRP in 1979, 1980, and 1981 when they adopted a limit for total alpha in ore dust which was over three times too high. After 1982, when Rössing claims to have adjusted their total alpha limit to match the ICRP requirement, they failed to calculate the appropriate radiological dust standard. They now claim that in 1982 they adopted a figure of 0.03 mg/m^3 when they should have adopted 0.025 mg/m^3 for uranium concentrate and 0.01 mg/m^3 for uranium in ore dust in order to comply with the ICRP recommendations published in 1979.

Dr Myers says[81] that the figures supplied in Tables 1 and 2 "are the same as those given in the various Codes of Practice published by Rössing over that period of time". If so, the Codes of Practice were wrong as well. But Dr Myers may have known that something was not quite right, as he then stated[82] that "the radiological standards for airborne uranium dust are essentially the same as those recommended by the ICRP". Perhaps "essentially the same" has a special technical meaning of "completely different".

Back in the Executive Summary this care with language is unnecessary and[83] "the codes of radiation protection practice from 1977 to 1992 are all consistent with the recommendations of the International Commission on Radiological Protection that were available at the time these codes were issued". Without seeing the Codes I cannot say. But if the numbers in Tables 1 and 2 are the same as those in the Codes of Practice, as Dr Myers tells us, then the Codes are definitely not consistent with the ICRP.

Finally, just suppose that the 1982 Rössing radiological uranium dust standard was 0.03 mg/m^3 (despite the Chief Environmentalist), not far from the ICRP standard of 0.025 mg/m^3 for uranium concentrate at that time. The actual uranium dust levels sampled in the final product recovery area[84] averaged 0.10 mg/m^3 with 29 per cent over 0.15 mg/m^3 and a peak of 0.35 mg/m^3. If the company adopted the appropriate ICRP standard despite the evidence they certainly flouted it in the final product recovery area in 1982.

Monitoring of radionuclides

The union also asked[85] the IAEA to comment on "the company's failure to monitor the environmental levels and personal exposure to Thorium 230, Polonium 210, Lead 210 and Actinium 227 at least up to July 1985..." According to Dr Myers[86] "this query is again based on a misunderstanding". He replies dealing with doses from "inhaled ore dust" where, as he observes, the various radionuclides are in equilibrium and need not be measured individually. As he says, this is true "up to the point at which the leaching process to remove uranium from crushed ore occurs". That is why Rössing should monitor the individual radionuclides in the mill and tailings where they become separated.

I am glad that the IAEA Tailings expert M Laraia took the point. He advises Rössing[87] that "a study should be conducted to assess the radiological implications of the presence of thorium isotopes and radionuclides of concern in the uranium decay chain (e.g. Lead 210) – depending on the study results, periodical monitoring of some of those radionuclides in airborne dust, seepage from the tailings dam and/or groundwater may be needed."

TAILINGS

Until the tailings decommissioning plan is published, no one outside the inner circle of engineering consultants and the IAEA can judge whether Rössing will be able in practice to comply with the standards of the US Environmental Protection Agency and Nuclear Regulatory Commission, although the plan apparently adopts standards which are "basically derived from those of the US Environmental Protection Agency".[88] The IAEA refrains from detailed comments pending the completion of the draft plan[89], and stays silent on the 16 year delay between the start of mining operations and the attempt to draft a decommissioning plan.

In the US, Canada, or Australia, approval of such a plan after public review is now a legal requirement before new mining projects may begin and decommissioning procedures were established in the US in 1978 with the Uranium Mill Tailings Radiation Control Act. It is therefore odd to read in the "General Conclusions"[90] the complete verdict: "The mill tailings management programme of Rössing, and the associated surveillance programme are of good standard and conform with the current international standards."

Seepage

Despite the "General Conclusions", M Laraia does refer to seepage discovered in 1981[91] and reveals that "investigations were then implemented for several years", as a result of which "the water table dropped and any visible seepage disappeared". This suggests that the seepage problem quantified in "Past Exposure" on the basis of company documents persisted for several years. The IAEA does not reply directly to the MUN's request[92] for information on the extent of past seepage in view of Rössing's estimate that in 1980 "perhaps 45 per cent of the seepage from the Tailings Dam was bypassing the collection system"[93].

The IAEA examined data for a borehole in the Khan River downstream of the mine and concluded: "It is possible that a residual contamination from the 1981 seepage is being flushed out". Other boreholes "were contaminated early in the '80s, but in the mid-80s monitoring was discontinued."[94]

Even in September 1992, "an unknown quantity of seepage also moves through fractures in geological formation. It is therefore recommended that all of the existing boreholes, cut-off trenches and dewatering wells be regularly monitored to get a more precise picture of the movement of the seepage front ... and variations in the radio-nuclide concentrations."[95] The positions of the seepage fronts in February 1990 are shown[96]; the Pinnacle Gorge front (below the seepage dam) was already very close to the junction with the Khan River.

The IAEA expert also points out[97] that seepage from the tailings dam is becoming increasingly acidic, posing the threat of an acid front carrying heavy metals and radionuclides. This danger was anticipated in 1988 by Thomas Siepelmeyer[98]. The May 1992 data given in Table II[99] shows a pH of 3.6 at the seepage dam compared with 6.5 in 1988.[100] As the IAEA recognises, the possibility of "an acid front moving through the groundwater system" would "indicate that the neutralizing capacity of the materials through which the solution has moved, has been exhausted" and the consequences "could be serious since heavy metals and some radionuclides are mobilized ... It must be predicted that the seepage pond will become acid enough to keep ferric iron in solution, and since this dam does pass some seepage down the Pinnacle Gorge, that an acid front could develop in the gorge." In its recommendations[101] the IAEA recognises "the buffering capacity of the tailings, soils and rocks are finite and non-renewable. The appearance of an acidic seepage is perhaps the indication that the buffering capacity is being exhausted."

The only hint of this risk in the Executive Summary is one cryptic sentence:[102] "However, environmental conditions are still to be closely watched as margins of uncertainty still persist, in particular for the long term." The "General Conclusions" omit any trace of seepage past or present.

However M Laraia recommends[103] "an environmental model to predict the environmental impact from a hypothetical worst-case contamination of the Khan River should be established. Particular emphasis should be given to radiation doses to the general public from irrigation, farming cultivation, livestock etc."

The IAEA points out that the Department of Water Affairs do not currently monitor for uranium and radium as part of their independent measurements of chemical parameters in groundwater, and recommends that "competent authorities should possess adequate material and human resources to inspect, cross-check or validate the results provided by the plant owner".

Water usage

The IAEA explain[104] that "water losses are particularly critical at Rössing as they have to be replaced by increased extraction from the Khan River or by fresh water provided by other sources." The seepage control strategy adopted in the wake of 1981 led to extensive recycling. As a result, the tailings pond "dried up and no more water could be recycled to the mine. Therefore the consumption of fresh water had to be increased again in 1987".[105] This led Rössing to adopt its current "paddock" system for depositing tailings. There is no explicit discussion of the changing impacts on water supply for the coastal region since 1976 – surely a key concern at the Dept. of Water Affairs – nor of possible health risks from the use of recycled tailings liquids in the mine and mill.

Dust

The IAEA recognises[106] problems with dust at the tailings dam which increased due to the "dry" strategy of recycling tailings liquids, and which are most severe during the strong East wind.

M Laraia notes[107] various failed attempts at dust control by Rössing: "Growth trials with different species of plants met

with little success" due to drought; "Placing of worn out truck tires to act as a wind breaker"; "cover(ing) the tailings surface by old fishing nets"; "putting a reed fence which acts as a wind breaker" – all of which were "only partially successful and can not be considered for the long term." The company is now experimenting with chemical sprays and alluvium covers, but there is no attempt to compare Rössing's efforts with US techniques employing ashes, clay or soils.

Significantly, the IAEA discloses[108] that "the first medium-scale test against radon, dust dispersion and run-off is scheduled for late 1992" – again, 16 years after mining began. M Laraia notes[109] that the radon exhalation rate is now only slightly higher than the US EPA standard, but does not mention the possibility that the rate will rise further when the decommissioned tailings dam dries out.

CONCLUSIONS

While recognising the valuable information contained within parts of the full report, I believe the evidence supports the general criticisms summarised earlier. It also raises questions about the performance of the IAEA as the UN agency partly concerned with ensuring safety and the protection of health in the nuclear industry. Such questions are often raised – e.g. concerning the Agency's confidence in the safety of the Chernobyl reactor in 1983 and their controversial study in 1991 of the after-effects of the 1986 disaster. The full report of their mission to Namibia, despite some important information, reinforces the impression that the IAEA is hardly an unbiased observer.

The mission ignored documentary evidence drawn to their attention, in writing, on arrival in Namibia. This evidence contradicts their findings. The IAEA's own findings contradict some of their "General Conclusions" which may be effective propaganda but are not justified by the facts. Anyone who still believes it is worth analysing the available evidence, drawing conclusions and then stating them openly, has no reason to accept this circus.

Workers will have to look to their own organising abilities and to supporters in the wider trade union, health and environmental movements for assistance with their legitimate concerns. ■

Sources:

1) Quoted in *Past Exposure.*
2) Interview conducted by Graham Hopwood of "*Church Action on Namibia* (see "Past Exposure" for this and other interviews).
3) *The Namibian* 10 Feb 89.
4) M A De Kock et al, Cross-sectional study of uranium mine workers to develop predictive equations for lung functions with reference to chronic obstructive pulmonary disease, Supplement to the *South African Medical Journal*, 19 March 1988.
5) 6 March 92.
6) *Rössing News* 13 March 92.
7) 9 March 92.
8) 13 March 92.
9) 18 April 92.
10) MUN Proposals, reproduced by the IAEA in Part 4, p 35 point (f).
11) IAEA Part 4 pp 38–39 points (n)1, 2 and 4.
12) Part I p 28.
13) Part I p 31 Figure 5.
14) Part 3 p 5.
15) Part 1 p 31 Figure 5.
16) See "*Past Exposure*" pp 98–99.
17) Executive Summary p 11.
18) Data from Appendix 3 of the Dec 1982 *Rössing Radiation Report.*
19) Part 1 p 31 Fig 5 and p 33 Fig 9.
20) Part 3 p 16.
21) Part 3 p 17.
22) 18 Sept 92.
23) Part 3 p 18.
24) It should have appeared in Exec Sum p 7.
25) Executive Summary p 12.
26) *Past Exposure* p 58.
27) Part 3 Figure 5 p 53.
28) Part 3 pp 18–19.
29) Exec Sum p 9.
30) Exec Sum p 12.
31) Exec Sum p 4–6.
32) It should appear in Exec Sum p 4.
33) Part 2 pp 9 – 10, p 15 and in final recommendations on p 19. The data appears in Appendix I Part 2 p 25.
34) Part 2 pp 9–10.
35) Part 2 p 10.
36) Part 2 p 19.
37) Exec Sum p 12.
38) Part 2 p 21.
39) Part 2 p 29. Arandis is the township originally constructed to house Rössing's black workers.
40) Part 2 p 23.
41) Part 2 p 24.
42) Part 2 p 15.
43) Exec Sum p 5.
44) Part 4 p 14.
45) Part 3 p 34.
46) Part 4 p 38.
47) Part 3 p 16.
48) Part 3 p 18.
49) Part 4, p 36 h1.
50) Dec 1982 *Rössing Radiation Report*, quoted in *Past Exposure* p 85.
51) Part 1 p 13.
52) Part 3 p 16.
53) Part 3 p 14.
54) Part 3 p 14.
55) Part 3 p 54 Fig.6.
56) Part 3 p 6.
57) Part 3 p 21.
58) Part 3 p 20.
59) Part 3 p 20.
60) Part 3 p 21.
61) Part 3 p 22.
62) Mortality among workers at Oak ridge National Laboratory Wing et al, *Journal of the American Medical Association*, March 20, 1991.
63) Part 3 p 29.
64) Part 4 p 38 point n2.
65) Part 3 pp 8–9.
66) 13 March 92.
67) Letters, *The Namibian* 6 Nov 92.
68) Letters, *The Namibian* 22 Jan 93.
69) *Past Exposure* p 57.
70) pp 80 and 86.
71) p 84.
72) Part 3 pp 8–9 and pp 30–33.
73) Part 3 p 50.
74) Part 3 p 47 Table 2.
75) Part 1 p 28.
76) Part 3 p 8.
77) Part 3 p 47, Table 2.
78) *Past Exposure*, p 86.
79) *Radiation Protection of Workers in Mines* Vol16 No1 1986 pp 7–8.
80) See ICRP 47 p 8.
81) Part 3 p 8.
82) Part 3 p 9.
83) Exec Sum p 6.
84) Rössing Radiation Report Dec 1982, Appendix 14.
85) Part 4 p 39.
86) Part 3 p 15.
87) Part 5 p 22.
88) Part 5 p 19.
89) Part 5, p 19.
90) Exec Sum p 12.
91) Part 5 pp 12–13.
92) Part 4 pp 37–38.
93) Quoted in *Past Exposure* p 110.
94) Part 5 p 15.
95) Recommendation 1, Part 5 p 21.
96) Fig 6 Part 5 p 35.
97) Part 5 p 13.
98) *Strahlende Geschäfte*, p 18.
100) Part 5 p 13.
101) Part 5 p 22.
102) Exec Sum p 10.
103) Part 5 p 22.
104) Part 5 p 7.
105) Part 5 p 7.
106) Part 5 p 16.
107) Part 5 p 17.
108) Part 5 p 17.
109) Part 5 p 18