IAEA-TECDOC-1244

Impact of new environmental and safety regulations on uranium exploration, mining, milling and management of its waste

Proceedings of a Technical Committee meeting held in Vienna, 14–17 September 1998

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

September 2001

The originating Section of this publication in the IAEA was:

Nuclear Fuel Cycle and Materials Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

IMPACT OF NEW ENVIRONMENTAL AND SAFETY REGULATIONS ON URANIUM EXPLORATION,
MINING, MILLING AND MANAGEMENT OF ITS WASTE
IAEA, VIENNA, 2001
IAEA-TECDOC-1244
ISSN 1011–4289

Printed by the IAEA in Austria
September 2001

FOREWORD

Concern for health, safety and the environment has grown rapidly during the past two decades. Exploitation of any mineral commodity, including uranium, involves the modification of the surrounding environment. Appropriate regulations governing such activities can assure good practices and minimize possible negative impacts on the environment and the health and safety of the workers and the general public. Unfortunately there is still a lack of information on what is considered as the natural environment in specific areas where projects are developed and upon which these regulations should be properly based, rather than on the perceived understanding of the general public.

During the past few years, a number of countries have promulgated new regulations related to uranium exploration, mining, milling and the related waste management. While many of the principles adopted generally follow a similar basis, their practical applications differ from country to country. It appears that many of these regulations are still at the evolutionary stage of implementation. Recent regulations are stricter in terms of environmental assessment, mitigation, radiation protection and control of waste. The impact of these regulations in developed countries has resulted in better planning of operations, improvement in mine and mill designs and a more efficient approach to tailings management.

There is still a need to have a more rational and uniform standard and approach to regulating mining activities that will assure safety to the workers, public and the environment, and at the same time not impede the production of a necessary mineral commodity. Furthermore, these standards should be based on actual risk that can be estimated from comparable activities.

The Technical Committee on the Impact of New Environmental and Safety Regulations on Uranium Exploration, Mining, Milling and Waste Management was held in Vienna from 14 to 17 September 1998 and was attended by 25 participants from 17 countries representing government organizations and private industry. The 21 papers presented provided information on new experiences in major uranium producing countries on the subject, past producers, as well as on country where regulations and related regulatory structure are still at the early evolutionary stage.

IAEA publications that have close relations to the theme of the meeting are: *(1) Guidebook on the Development of Regulations for Uranium Deposit Development and Production, IAEA-TECDOC-862 (1996); (2) UPSAT Guidelines — 1996 Edition Reference Document for IAEA Uranium Production Safety Assessment Teams (UPSATs)*, *IAEA-TECDOC-878 (1996), (3) Environmental Impact Assessment for Uranium Mine, Mill and In Situ Leach Projects, IAEA-TECDOC-979 (1997).*

The IAEA is grateful to all participants. The IAEA staff member responsible for this publication was J.P. Nicolet of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

SUMMARY

The nuclear industry has been subjected to intense public scrutiny since the event at Three Mile Island and the Chernobyl accident. It is obvious that the general public should be properly informed on happenings that might affect their health and safety. It is quite often, however, that a great number of these concerns are based on subjective misinformation that are out of proportion to the potential risk that could result from such an operation. Uranium exploration and production, to a certain degree are also subject to this scrutiny.

During the past few years a number of countries have promulgated new regulations related to uranium exploration, mining, milling and the related waste management. Regulations governing the uranium industry are in most cases country specific. However, the general trend in the new regulations being drafted and/or implemented can be summarized as follows:

(1) A request for detailed environmental impact assessment and implementation of mitigation measures during the life of the operation.
(2) A strengthening of radiation protection for all aspects of the operation.
(3) Strict control of solid and liquid waste.
(4) The establishment of decommissioning plans during the life of the operation.
(5) Financial provisions from the operator for closure.

The drafting and implementation of regulations are at different stages in developed and developing countries.

In the developed countries, market conditions for the past 15 years resulted in the termination of many operations. During this same period industry undertook a number of technological changes to meet market conditions and new regulations. The positive impacts of new regulations in developed countries are a thorough assessment of the environmental impacts; better planning of operations; from exploration, development and exploitation; improvements in mine and mill designs in the reduction of waste; and more efficient use of mine and mill waters through recycling. Tailing disposal technologies have also progressed to meet new regulations, a major issue in mine operations.

There is a lack of information on natural global geochemical and radiation background, from which regulations that deal with the earth's environment should be based. This is considered to be the main reason why a number of regulations are judged too strict and disproportional to the generated risks caused by these activities. These over restrictive regulations have a negative impact on future development of operations. Several papers presented at the meeting addressed this subject and concluded that the uranium industry is over regulated.

Dealing with new regulations related to uranium production, closure, and eventual decommissioning and remediation, still encounter problems connected with the organizational framework of the multi-layers of regulators and the required infrastructure to implement and support them. It may be concluded that a good and practical model is needed to avoid unnecessary delays and additional costs. Otherwise this type of regulations could have adverse effect on uranium production in most countries.

For many of the developing countries, the situation regarding regulation is different as regulations are often at the drafting stage and are sometime considered by politicians, as not bringing any benefits to the economy of the country. Implementation of regulations is slow or

at times at a standstill due to improper funding. This is one of the reasons why some consumer countries conduct environmental audits that will help assure that the imported materials were produced in accordance to internationally accepted practice. Such an audit could force supplier countries to adopt a standardized approach of operation and may indirectly help implementing the proper regulations and international standards that are necessary for economic development.

The objective of the meeting was to obtain information from the regulators and the industry on the impacts, both positive and negative, of the new regulations being implemented for uranium exploration and production in their respective countries. The 21 papers presented at the meeting addressed the following points:

(1) Lack of general public understanding of radiation in everyday life and the perceived associated risk;
(2) Existing regulations and related processes that are often based on this misunderstanding, and incomplete data thus generating unnecessary and unrealistic requirements;
(3) Difficulties experienced by newly emerging and developing countries in adopting and implementing the new regulations that are based on internationally acceptable standards;
(4) Lack of comparable regulations for similar activities, i.e. phosphate and coal mining; and
(5) A new trend for the need to conduct customer oriented environmental audits in the supplier countries.

The participants prepared the following conclusions regarding the important issues raised in the papers given during the meeting:

(1) A strong regulatory framework is important for the credibility of the industry, but this does not mean that regulations must be unnecessarily strict. Realistic regulations must be developed, which will apply to a wide range of developments and which will allow developing countries to participate. Regulations of the style applied to reactors may have some application to vary high grade operations, but low grade deposits and by-product recovery operations, etc., need a different style of regulation. Rather than more regulations, better regulations are needed, in particular clearer ones. Public relations are important, however, the issue are quite often social rather than technical. The public perception of radiation risk needs to be addressed, because this is often the driving force for stricter regulation.
(2) Where there is more than one level of government, it is important to have an agreement to have a single set of regulations, inspections and reports. Overlapping and conflicting jurisdictions should be avoided.
(3) Site-specific codes of practice are essential. Unlike a reactor installation, which can be designed to any particular level of protection, an ore body is a natural phenomenon and each one is unique with its own set of unique problems.
(4) In environmental assessments, it is suggested that the level of effort should be commensurate with the real potential risks of the operation, as opposed to publicly perceived risks. If care is not taken in setting environmental criteria, unnecessary costs may be incurred. It is not sensible to define concentrations in water to meet drinking water limits, if the water cannot be used now and in the future as drinking water.

Drinking water standards should apply where water is or will be used for drinking, but in other circumstances they may be unnecessarily restrictive.

(5) ALARA analysis must include non-radioactive elements. It is foolish to spend large amounts to control very small risks when toxic chemicals produce a much greater risk. As an example, when would the risk of the barium addition in water treatment outweigh the risk from the radium that is being removed?

(6) Regulations should be risk based. Radioactivity should not be over-emphasized when other hazards are of equal or greater importance. Comparisons should be made between radiation risk and other industrial risks. This has three applications: decisions on the type of power system a country employs (fossil, nuclear, solar, etc.); placing radiation risks into perspective for the public.

(7) The problems associated with stable contaminants are often worse than the problems with radioactivity.

(8) Radiation protection problems extend beyond uranium and thorium mines and processing operations. Other underground mines, in particular phosphate mines, have similar problems and often fall through the cracks in a regulatory system.

(9) It is essential to explain very clearly how radiation dose measurements are made and how doses are calculated. Different dose conversion factors used by different member states lead to confusion in impact assessments and could lead to serious trade disadvantages for some states.

(10) In environmental assessments the level of effort should be commensurate with the real potential risks of the operation, indicated by the regulators, as opposed to publicly perceived risks.

(11) Developing countries should develop simpler regulatory systems that are applied with professional judgment and according to the type of risks defined by their resources. The level of regulatory complexity should be based on a graded approach applicable to the local conditions of the country.

(12) Some level of institutional control of a site after decommissioning and closure is advised if the site contains stored wastes. Since States generally last longer than Companies, it is advisable to have such sites revert to the State when the last company leaves a site.

(13) Provisions for financial assurance for decommissioning and closure should be recovered in the course of the operation of the facility. Financial provisions should be flexible and they should not place such a burden on the operator that they restrict his ability to do business.

(14) Caution is advised in the rigorous application of the recommendations of ICRP 60. Mining is a major source of foreign exchange in some developing countries. Putting their mines out of business with stricter regulations would cause greater hardship than the radiation exposure of the workers.

THE ROLE OF ELECTRICITY UTILITIES IN ENSURING ENVIRONMENTAL COMPLIANCE OF URANIUM SUPPLIERS

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Abstract

The Swedish Utilities: Vattenfall Fuel, OKG and BKAB (purchasing uranium and fuel cycle services for all Swedish reactors) have started "Nuclear Fuel and Environment Project, NFE". The purpose is to make environmental audits of companies with uranium mines, conversion, isotope enrichment and fuel fabrication facilities. Up to now five environmental audits have been carried out and another three are being processed.

1. WHY ENVIRONMENTAL AUDITS?

There were principally three reasons for the Swedish utilities to start this Customer Oriented Environmental Audit:

- Swedish and International large electricity consumers require environmentally acceptable electricity production;
- There is political pressure to demonstrate that nuclear power is environmentally acceptable and the nuclear fuel cycle is in focus;
- Swedish Nuclear Power Plants want to adhere to Environment Management Systems such as ISO 14001 and/or EMAS, and then they must be assured of an acceptable environmental status of their suppliers.

2. THE ORGANIZATION

The Nuclear Fuel and Environmental Project has a Steering Group with members from the Swedish utilities. The Chairman is Mr. Stig Sandklef, Vattenfall Fuel. NFE has a small secretariat, now two people. When a team is selected, usually specialists from the Swedish utilities participate together with one or two independent specialists. A normal team is around five people.

3. THE PROCEDURE

The procedure for an NFE Environmental audit is:

- criteria are sent to the Supplier Company;
- written answer are sent to NFE;
- Swedish team verifies the environment by visiting the facility, discussions with the company's specialists in environment and work environment including radiation safety, and discussions with regulatory authorities;
- a preliminary report is written, sent to the company for checking;
- a final report is written.

4. THE CRITERIA

The NFE criteria have been developed from the ISO 14001 criteria, however these are not sufficient. We want also to include work environment and radiation safety. The criteria have been discussed with utilities, industrial organizations and regulatory authorities in Sweden, as well as with international organizations such as The Uranium Institute (UI) and International Atomic Energy Agency (IAEA).

In addition, NFE requests data such as emissions to air and water and radiation doses to personnel.

The criteria comprise the following areas:

- international standards;
- national laws;
- permissions (licences, authorizations);
- environmental policy;
- implementation of environmental policy;
- work environment including radiation safety;
- treatment of chemicals;
- waste, mill tailings;
- annual report, environment;
- incidents;
- decommissioning and restoration.

5. THE ENVIRONMENTAL AUDIT

The environmental audit is carried out in accordance with the standards ISO 14010, ISO 14011 and ISO 14012, with the addition that NFE also takes contact with regulatory authorities to listen to their views. The team carrying out the verifying visit comprises about five people. The team usually includes specialists in environmental management systems, work environment and radiation protection. The team includes specialists from the utilities as well as independent specialists. The teams comprise different specialists for each environmental audit.

The final reports are delivered to the Swedish utilities. As the utilities finance the audits, the reports are their property. A typical report is 30–50 pages including annexes. The reports comprise all the elements for judgment if a company has an adequate environmental level for supplying uranium or nuclear fuel cycle services to the Swedish utilities. Each individual utility judges if the environmental level is adequate.

If a utility should find that the environmental level from one supplier is not adequate, this will certainly not be announced internationally. However the utility will discontinue purchasing from that supplier.

6. EXPERIENCES

The NFE has up till now carried out the following environmental audits in accordance with the procedure:

Company	***Facility***	***Activity***	***Country***
Priargunsky Mining	Krasnokamensk[1]	Uranium	Russia

[1] In co–operation with the Swedish Radiation Protection Institute.

ERA	Ranger	Uranium	Australia
Rio Tinto	Rössing	Uranium	Namibia
Elektro Chemical Plant	Zelenogorsk	Enrichment	Russia
Navoi Complex	Uchkuduk etc.	Uranium ISL	Uzbekistan
ABB ATOM	Västerås	Fuel Fabrication	Sweden

In addition, NFE also reviewed environmental issues at the uranium mines Key Lake in Canada and Olympic Dam in Australia.

The following environmental audits are in process:

BNFL	Springfields	Conversion	United Kingdom
URENCO	Capenhurst	Enrichment	United Kingdom
COMURHEX	Malvesi, Pierrelatte	Conversion	France

7. COMMUNICATION WITH THE PUBLIC

Obviously NFE answers questions from the public in Sweden about the environment at uranium mines and fuel cycle facilities. As Sweden has no operating uranium mines, there is nobody else to answer such questions.

The Information Centers at the Nuclear Power Plants are interested in the NFE Project, as they often have visitors asking questions about uranium, conversion, enrichment and nuclear fuel fabrication. NFE has started to produce short versions of the environmental reports – four pages in Swedish language – for distribution to interested visitors.

NFE also has translated the Uranium Institute’s UI FACTS to Swedish on "Safety and Environmental Issues in Uranium Mining and Milling, Conversion, Enrichment and Fuel Fabrication", produced by the Uranium Institute SEA Working Group.

8. THE FUTURE

The "Nuclear Fuel and Environment Project" started formally on 1st January 1997, although we commenced some activities earlier. It is an example of a "Customer Oriented Environmental Audit".

The Criteria and the procedure are still being developed. We are trying to learn from our own experience as well as from others.
The Finnish Utility TVO recently decided to join the environmental audit of URENCO Enrichment Facility at Capenhurst and the COMURHEX’ Conversion Facilities at Narbonne and Pierrelatte, and we hope that this co–operation will continue.

NFE still has to carry out environmental audits at several companies that supply uranium, conversion, enrichment or fuel fabrication for the Swedish utilities – and in addition there is an interest of the Swedish utilities to carry out environmental audits at potential suppliers.

The NFE experience up till now is that all suppliers we have asked to participate in this Environmental Audit Procedure have co–operated very well. Actually, now several new potential suppliers are interested in NFE coming to them to perform an environmental audit of their facility.

LONG TERM POPULATION DOSE DUE TO RADON (Rn-222) RELEASED FROM URANIUM MILL TAILINGS

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Abstract

The results of a study undertaken by the European Commission on the external costs (environmental and social) of various energy production systems is likely to be influential in determining how the European Union will develop its energy supply systems. The estimated costs for nuclear power from the study will be based on the findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), with the costs being dominated by the estimated long term (10 000 y) population doses due to radon (Rn-222) released from mill tailings. UNSCEAR developed a central estimate of 150 person-Sv per GW y and a range of 1 to 1,000 person-Sv per GW y. However, the generic data available to and being used by UNSCEAR are dated and are not appropriate for the current and planned future conditions in the uranium production industry, with the result that the estimated external costs of nuclear power (specifically, the doses due to radon emitted from mill tailings) are overestimated. The Uranium Institute sponsored a study to estimate long term population doses based on the most recent 1993 UNSCEAR methodology, but using data that would be more appropriate to the current major uranium production facilities. Site-specific information obtained from the owners/operators and the Uranium Institute included: present and proposed tailings management plans; tailings volumes and areas; ore grades and reserves; measurements and estimates of radon emission rates; and population densities. Tailings at closed facilities that no longer contribute to uranium production were not evaluated since it was assumed that these radon sources need not be considered in evaluating the external costs of current and future nuclear power production. Based on the same approach as UNSCEAR, but using a more sophisticated air dispersion model, and more site-specific data relative to existing sites and proposed tailings management practices, radon emission rates and population densities (that had not been available to UNSCEAR), this study estimated the long term (10,000 y) population dose due to the emission of radon from (future) uranium tailings to be 0.96 person-Sv per GW y, i.e. about a factor of 150 below the UNSCEAR central estimate of 150 person-Sv per GW y. This is an average value for the eight sites examined in this study, weighted according to the most recent (1997) uranium production rates for the sites. The population doses for every site were below UNSCEAR's central estimate, while the estimates of population doses for six of the sites were below UNSCEAR's suggested lower range estimate of 1 person-Sv per GW y.

1. INTRODUCTION

Background

The European Commission has undertaken a study on the external costs (environmental and societal) of the various energy production systems, including nuclear power. The results of the study are likely to be one of the factors considered in determining how the European Union will develop its energy supply system. As a result, the study is of great interest to the nuclear industry, both in Europe and elsewhere. The Uranium Institute, the international trade association of the nuclear industry with some 78 members around the world, was asked by its membership to monitor the Commission's study, particularly with respect to nuclear power.

It came to the attention of the Institute that the radiation-related components of external costs for nuclear power are being based on the findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), with the costs being dominated by the estimated long term (10,000 y) collective population doses due to radon (considered to mean radon-222 hereinafter) released from abandoned (but stabilized) tailings. Unfortunately, the data used by UNSCEAR [1] are no longer appropriate for current and likely future conditions in the uranium mining industry, with the result that the estimated external costs of future nuclear power (potential environmental and societal costs) are overestimated.

Because of the importance of this issue to the nuclear industry in Europe and the worldwide uranium mining industry, the Institute retained SENES Consultants Limited to undertake a study using data that would be more current and appropriate for estimating population doses from radon, and therefore assist UNSCEAR in updating its estimates. The results of the SENES study [2] are presented in this paper.

It is important to understand that the objective of this study was to examine long term population doses due to radon released from uranium mill tailings as it relates to the present and future generation of electrical energy. Since long term (10,000 y) population doses were being evaluated, radon release rates appropriate to tailings after decommissioning were considered. The releases during mining and prior to decommissioning are relatively of very short duration (generally less than 50 y) and were not considered in this study.

The collective population dose is proportional to the assumed duration of release. UNSCEAR [1] chose this value to be 10,000 y "for the sake of illustration". This value was also used in this study in order to compare the results to the UNSCEAR estimates.

Additionally, since radon from previously closed-out facilities will be released irrespective of the future of nuclear power, it was assumed that these sources need not be considered a factor in evaluating the externalities of current and future nuclear power production. For example, UNSCEAR [1, p.136] shows that sites in the Elliot Lake, Ontario region of Canada were the dominant sources of tailings-radon in Canada (up to 1989). However, all these mines are closed and are no longer producing uranium, and the largest tailings areas are water-covered, thus eliminating the radon source term. The mines in western Canada (Saskatchewan) will be essentially the only source of Canadian uranium for nuclear power for the foreseeable future, and were the Canadian radon sources examined in this study.

A similar approach was taken in selecting the sites in other countries that were examined in this study. Essentially, the major uranium production facilities currently existing were examined in order to provide a "snapshot" of present-day and likely future tailings management site conditions.

Tailings sites examined

In order to determine values of radon population doses that would be more representative of present day and likely future conditions than the values used by UNSCEAR, it was decided by the Institute that a survey of the major uranium production facilities be conducted. Information on radon release rate, tailings volumes, ore grades and production rates, likely decommissioning plans, and population densities was requested from various operators. It was requested that the information be based as much as possible on site-specific data.

The major mills in terms of uranium production in the 1995-97 period are shown in Table I [3]. These were the facilities examined in this study. These facilities currently (1997) represent 67% of worldwide uranium production.

TABLE I. MAJOR URANIUM PRODUCTION FACILITIES (1995-97) [3]

Country	Mill Facility	Owner/Operator	Production (t U)		
			1995	1996	1997
Canada	Key Lake	Cameco/Uranerz	5,461	5,423	5,433
Canada	Rabbit Lake	Cameco/Uranerz	3,154	3,962	4,632
Australia	Ranger	ERA (Energy Resources of Australia)	2,550	3,508	,095
Namibia	Rössing	Rio Tinto (66%)	2,007	2,452	2,905
Niger	Akouta	COGEMA/Onarem	1,960	1,960	2,100
Canada	Cluff Lake	COGEMA	1,200	1,900	1,950
Australia	Olympic Dam (co–product with copper)	WMC (Western Mining Corporation)	1,108	1,466	1,425
Niger	Arlit	COGEMA/Onarem	***1,000***	***1,200***	***1,350***
		Total:	18,440	21,871	23,890
	% of total world production:		56%	62%	67%
	% of total world production less ISL:		65%	71%	77%
In-situ leach (ISL) facilities (est.)			***4391***	***4400***	***4601***
		Total world production:	32,916	35,199	35,448

Although not specifically examined in this study, *in situ* leach (ISL) facilities, which currently represent about 13% of worldwide uranium production, have no surface tailings and little radon emissions after closure (e.g. [4]). Assuming the radon emissions from ISL facilities to be negligible, the results of this study could be considered to represent the impacts of long term radon emissions based on 80% of current uranium production.

The information used in this study can therefore be considered representative of worldwide conditions at the major uranium production facilities under current and foreseeable future tailings management practices.

Study approach

Similar to the approach used by UNSCEAR, this study was limited to the use of modelled, generic air dispersion factors that were considered to be applicable to all sites. However, because of the potentially large (and unknown) uncertainties associated with this approach, and because of the availability to SENES of other air dispersion information for North America from previously completed projects, as well as census population data for Canada, more site-specific analyses were carried out for the Canadian sites. Access to these data facilitated estimates of population doses using both actual and uniform population distributions, as well as comparison of air dispersion factors for a northern latitude site with results from a mid-latitude site (Mexico) for which air dispersion parameters had also been compiled in the previous completed projects by SENES. By means of this comparative analysis, it was intended that the variability in the population doses and long-range dispersion factors for two such quite different locations could be investigated and, in turn, would assist in quantifying the potential uncertainties associated with the use of the same dispersion estimates for all tailing sites.

2. UNSCEAR ESTIMATES

UNSCEAR makes use of generic radon fluxes to estimate radon release rates and a generic air dispersion model to estimate the environmental radon concentrations as a function of distance from the site. UNSCEAR then converts the concentrations to population doses using assumed areal population densities out to a distance of 2000 km and a radon dose conversion factor. Doses are accumulated over an assumed long term exposure period (10,000 y). The results are normalized to a unit amount of electrical energy produced. A summary of UNSCEAR assumptions, some of which were originally derived in [7], is given in Table II. These UNSCEAR assumptions are discussed below.

Uranium fuel requirements

The 210 t of uranium (250 t U_3O_8) required to produce 1 GW y of electrical energy is dependent on the reactor type, ranging from 180 t of uranium for heavy water reactors to 330 t of uranium for Magnox reactors [1, p. 105].

Normalized tailings surface area

The basis for the 1 ha per GW y value is not given (originally used in [5, p. 140]). However, for perspective, the thickness of tailings, with a density of 1.6 t m^{-3} and a surface area of 1 ha, resulting from the production of 210 t of uranium from 1% uranium grade ore, would be about 1.4 m (assuming 92% recovery). This value is inversely proportional to the grade, with 0.3% ore requiring a thickness of about 4.8 m. In practice however, tailings usually exceed these thicknesses, at least for the sites examined in this study, and therefore the area per unit of electrical energy produced is usually less than that assumed by UNSCEAR. (The areal radon rate per unit surface area does increase proportionately with ore grade, but only minimally with increasing thickness beyond the first couple of metres of tailings).

TABLE II. UNSCEAR ASSUMPTIONS USED TO DERIVE POPULATION DOSE ESTIMATE FOR LONG TERM RELEASE OF RADON FROM URANIUM MILL TAILINGS[1]

Uranium fuel requirements:	210 t U (250 t U_3O_8) per GW y of electrical energy
Normalized tailings surface area:	1 ha per GW y
Radon release rate:	3 Bq m^{-2} s^{-1}
Normalized emission rate:	1 TBq y^{-1} per GW y
Population density:	3 km^{-2} < 100 km 25 km^{-2} 100 - 2000 km
Air dispersion factor at 1 km: (release from semi-arid area at an effective height of 10 m)	3 x 10^{-6} Bq m^{-3} per Bq s^{-1}
Reduction in concentration with distance:	$X^{-1.5}$ (X in km)
Dose conversion factor: (equilibrium equiv. Radon conc.)	9 nSv h^{-1} per Bq m^{-3} (EEC)
Radon progeny equilibrium factors:	0.4 (indoors, occupancy 80%) 0.8 (outdoors, occupancy 20%)
Collective effective dose factor:	0.015 person-Sv per TBq
Cumulative exposure period:	10,000 y
Collective effective dose (range):	150 (1 to 1000) person-Sv per GW y

1. Sources: [1, 5, 6, 7].

Radon release rate

The UNSCEAR unit radon release rate is based on reported emission rates ranging around 10 Bq m^{-2} s^{-1}, and the assumption that some reasonably impermeable cover would reduce the rate to 3 Bq m^{-2} s^{-1} [1, p. 106; 5, p. 140]. The rate is assumed to be unchanged over at least 10,000 y because of the long radioactive half-life (80,000 y) of Th-230, the precursor of Ra-226.

As described in the next chapter, this rate substantially exceeds the rate expected for most of the tailings sites examined in this study, due to the planned covers and/or saturation of the tailings.

The normalized emission rate of 1 (actually 0.946) TBq y^{-1} per GW y [1, p. 106) is derived from the previous assumptions.

Population density

The assumed population densities for the reference tailings site of 3 and 25 persons km^{-2} in the <100 km and 100 to 2000 km regions, respectively [1, p.106], were originally derived from a 1975 study of tailings sites in the United States [7, p.168].

While not unreasonable values for the rural, Southwest United States, these densities are significantly greater than the densities derived for the sites examined in this study (Section 3). The final estimate of the population dose is directly proportional to the assumed population density.

Air dispersion factors

The average air dispersion factor at 1 km and its reduction with distance for the model site were derived in part from a Gaussian plume model with a nominal source release height of 10 m and various assumptions about atmospheric conditions [6, 7]. The factor at 1 km is 3 x 10^{-6} Bq m^{-3} per Bq s^{-1}. Beyond 1 km, and it was assumed that the concentrations decreased as $(\text{distance})^{-1.5}$.

If the assumed population densities and air dispersion factors are combined, and the radon progeny equilibrium factors (see below) are assumed to be constant with distance, then the total population dose is proportional to:

$$P_1 \times \int_0^{100} r^{-1.5}\, 2\pi r\, dr \;+\; P_2 \times \int_{100}^{2,000} r^{-1.5}\, 2\pi r\, dr$$

where: P_1 and P_2 are the population densities (persons km^{-2}) in the <100 km and 100–2000 km regions, respectively. Integrating equation 2.1 indicates that about 97% of the estimated population dose is for people living more than 100 km from the site for the population densities assumed by UNSCEAR. For a uniform population density across both regions, about 78% of the population dose would be for people living in the 100–2,000 km region around the site.

It is not clear if UNSCEAR includes the decay of radon (3.82 day half-life) in their dispersion calculations. At a distance of 2000 km, and with an assumed 2.5 ms^{-1} average windspeed, the decay would reduce the radon concentrations by about a factor of 5.

Dose conversion factor

The dose conversion factor of 9 nSv h^{-1} per Bq m^{-3} (equilibrium equivalent concentration, EEC) [1, p. 54] is based on now superseded dose factors that were derived using a dosimetric approach.

Subsequent to the publication of [1], the ICRP [8] published a revised radon dose conversion factor for members of the public (derived by the ICRP using an epidemiologic approach). The factor is 4 mSv per WLM (working level month) and is equivalent to 6.4 nSv h^{-1} per Bq m^{-3} (EEC), the value used in this study. (Based on the results from a recent meta-analysis of major epidemiological studies by Lubin et al. [9], an even lower dose conversion factor as suggested by Lowe and Chambers [10] of less than 2 mSv per WLM may be appropriate).

Radon progeny equilibrium factors

The radon progeny equilibrium factors [1, p. 54] were based on several reported studies relative to typical background conditions, although there is some suggestion from some European and U.S. studies that 0.6, rather than 0.8, might be a more representative outdoor factor. Using the 0.6 value would slightly reduce the time-weighted average equilibrium factor (considering indoor and outdoor occupancy) from 0.48 to 0.44.

These factors refer to typical background conditions. However, when relatively close to a source of radon, such as uranium tailings, the outdoor factor is much lower because there is insufficient time for radon progeny in growth. For example, for an assumed 2.5 m s^{-1} average windspeed, the outdoor equilibrium factor at 1 km from a radon source would be about 0.1. (The indoor factor would be dependent on the air exchange rate of the building).

Collective dose factors

The final estimate of the collective dose is directly proportional to the assumed cumulative exposure period of 10,000 y. UNSCEAR [1, p. 107] acknowledges that the estimated result of 150 person-Sv per GW y (the same estimate obtained by UNSCEAR [5, p. 140] is highly dependent on a number of assumptions, including future tailings management practices, and they suggest a range from 1 to 1000 person-Sv per GW y about their central estimate. The numerical basis for UNSCEAR's quoted range is not given.

3. RADON SOURCE TERMS AND POPULATION DENSITIES

For this assessment, radon releases from the major, operating uranium production facilities were considered in the evaluation of the post-decommissioning source terms. The analysis did not consider radon from tailings areas no longer in use or which have previously been decommissioned. Similarly, as done by UNSCEAR, radon from mining and milling operations and from waste rock with residual trace radioactivity were not included in this analysis.

In order to develop a better understanding of the potential source terms, the operators of the major currently producing facilities were sent information requests. The following source term descriptions and population densities for the various sites were based on the responses, and on information supplied by the Uranium Institute and derived from publicly available literature.

The post-decommissioning radon source term estimates are summarized in Table III. The population density estimates are summarized in Table IV. The bases for these estimates are in given in SENES [2].

TABLE III. ESTIMATED LONG TERM RADON EMISSIONS FROM URANIUM TAILINGS SITES AFTER DECOMMISSIONING

Country	Mill Location/Name	Ore Grade (% U)	Area (ha)	Flux ($Bq\ m^{-2}\ s^{-1}$)	Emission Rate[2] ($MBq\ s^{-1}$)	Reference	Comments
Australia	Ranger	0.30	63	0	0	[11, 12]	Long term flux based on 12 m rock cover.
	Olympic Dam	0.051	720	0.2	1.44	[13, 14]	Flux estimated for proposed rehabilitation plan.
Canada	Key Lake[1]	13	24	0	0	This study	Tailings water-saturated and covered.
	Rabbit Lake	1.9	14	0	0	This study	Tailings water-saturated and covered.
	Cluff Lake	0.51	29	7	2.03	[15]	Based on current decommissioning strategy (thickened tailings and 1 m cover).
Namibia	Rössing	0.0298	750	1.2	9.00	[16]	Based on measurements on uncovered tailings; no reduction for future decommissioning assumed.
Niger	Akouta	0.43	50	0.10	0.050	[17]	Flux estimated for future covered tailings (above a background flux of about 0.05 $Bq\ m^{-2}$). Ore grades based on mill averages to 1996.
	Arlit	0.29	50	0.10	0.050		
UNSCEAR model				3		[1]	Area normalized to 210 t U and 1 ha per GW y.

1. Key Lake tailings refers to tailings produced from both Key Lake ore and McArthur River ore to be milled at the Key Lake mill.
2. The number of significant figures shown should not be considered indicative of the precision of the estimates.

TABLE IV. POPULATION DENSITY AROUND URANIUM TAILINGS SITES

Country	Mill Location/Name	Population Density (km^{-2}) < 100 km	100-2000 km	Reference
Australia	Ranger	0.054	1.8	[11, 12]
	Olympic Dam	0.21	1.5	[2, 13]
Canada	Key Lake	0.034	2.6	[2]
	Rabbit Lake	0.034	2.6	[2]
	Cluff Lake	0.034	2.6	[2]
Namibia	Rössing	2.1	5.2	[16]
Niger	Akouta	3.3	7.2	[17]
	Arlit	3.3	7.2	[17]
UNSCEAR model		3	25	[1]

4. AIR CONCENTRATION MODELLING

Modelling of long range transport requires sophisticated models, comprehensive meteorological data and extensive set-up effort. Existing data were available at SENES from previous studies to model long range transport for North American sites and two sites were selected. The first site was applicable to northern Saskatchewan meteorological conditions and the Canadian uranium mill tailings examined in this study, while the second (Mexico) was taken as representative of mid-latitude meteorological conditions. Analysis of the dispersion patterns for these two quite different regions provided information on how dispersion with distance varied. This analysis thus allowed some insight into the variability in the patterns of dispersion with distance that could be anticipated for mine sites at different locations. It was the intention of this analysis to illustrate the possible range of uncertainty associated with using the same air dispersion factors for all sites.

Site-specific modelling for a northern latitude site

The dispersion modelling for northern Saskatchewan used information and methodology previously developed for a study of the long-range pollutant transport in North America [18]. The U.S. Environmental Protection Agency (EPA) CALPUFF/CALMET modelling package was used to address long-range flow patterns and the earth’s curvature. Meteorological conditions were estimated for a 100 km by 100 km grid. Set-up effort is extensive for this type of modelling and, therefore, such detailed modelling could not be applied to other sites within the constraints of this project.

Concentrations from 100 to 2,000 km were estimated using the CALPUFF/CALMET model and the existing data available to SENES. The U.S. EPA ISC3 model was used to model concentrations from 1 km out to 100 km. The ISC3 model requires less set-up effort and provides reliable estimates over this range of distances.

The modelled source, located at 58N 103W and at a height of 1 m, had an emission rate of 1.0 Bq m^{-2} s^{-1} over a 250,000 m^2 area source for a total release rate of 0.25 MBq s^{-1}.

Modelled concentrations

Theory predicts that concentration drops off quickly, by much more than a factor of r^{-1}, close to the source due to the combination of rapidly increasing area with distance and due to vertical mixing. At larger distances, concentrations tend to drop off by no less than r^{-1} since the mixing heights limit the vertical dispersion.

It is not clear if the UNSCEAR air dispersion modelling was done accounting for radioactive decay of radon (half-life of 3.82 days). As a result, the radon concentrations may be overestimated for this reason, especially at large distances from the source. For this study, a correction for removal of radon due to radioactive disintegration was developed based on the time required for the radon to reach the location. The average duration of transport from the source to the receptor was approximated by dividing the distance by a 2.5 m s^{-1} average wind speed. For example, the duration of transport to a receptor 2,000 km from the source would be 9.3 days.

The corrected concentration (c) of radon at a receptor was approximated by:

$$c_{corrected} = c_{modelled} \, x \, e^{-\lambda_r t}$$

where:

λ_r = is the radioactive decay rate, 2.1 x 10^{-6} s^{-1}, of radon

t = is the elapsed time between release at the source and arrival at the receptor. The time was estimated by dividing the distance by a speed of 2.5 m s^{-1} (as estimated from the North American meteorology).

The method estimates that radon concentrations at 2,000 km distance from the source would be about 19% of modelled values assuming no radioactive decay (about a factor of five lower).

Concentrations were summarized for 16 directions from the source and the mean, maximum, and minimum concentrations are plotted on Figure 1 in comparison to those predicted by UNSCEAR dispersion factors. Concentrations drop off rapidly with distance with mean levels decreasing from about 300 mBq m^{-3} at 1 km from the source to 0.3 mBq m^{-3} at a distance of 100 km (a factor of 1,000 lower). The mean concentration is lower than 0.001 mBq $m-^{3}$ at a distance of 2,000 km and continues to drop at increasing distances due to both ongoing dilution and the radioactive decay of radon. The ratios of the predictions using the UNSCEAR dispersion model to the predicted mean values in this study range from about 2 at a distance of 10 km to 17 at a distance of 2,000 km.

The incremental radon levels at all distances are much lower than typical outdoor radon concentrations which are in the order of 10,000 mBq m^{-3} [1, p. 54].

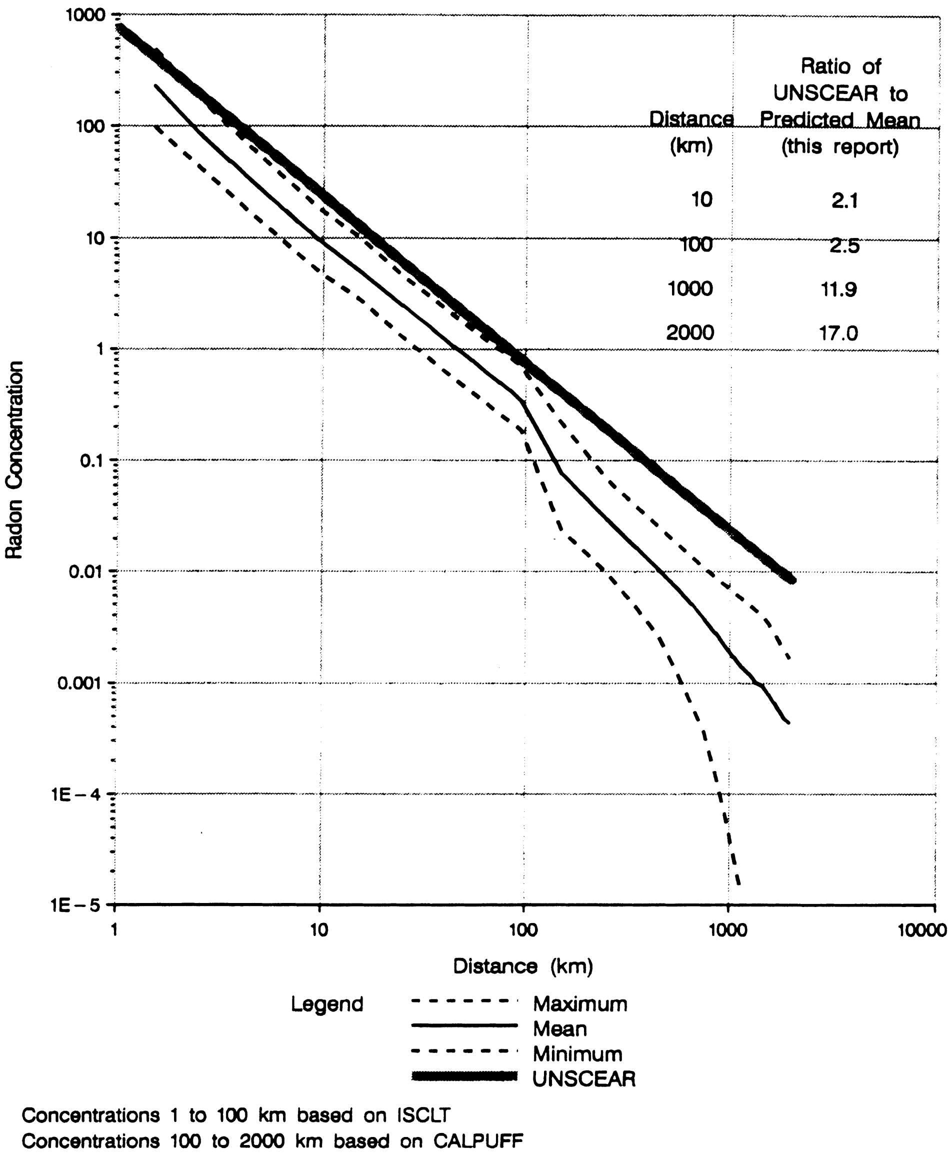

FIG. 1. Predicted radon concentrations (mBq^{-3}) with distance for Northern Saskatchewan site.

Modeling a mid-latitude site

Radon concentrations were estimated for the 100 km by 100 km North American grid with the source located at 25.5 N and 103.0 W in Mexico. Although no uranium facility is present at this location, the site was selected to illustrate dispersion characteristics in the mid-latitudes of the Northern Hemisphere.

Figure 2 shows the pattern of concentrations with distance for both the northern Saskatchewan and mid-latitude locations for distances of 100 to 2,000 km from the source in comparison to concentrations predicted using UNSCEAR's dispersion model. Mean concentrations for the mid-latitude location are higher (by about a factor of 2) than those calculated for the northern Saskatchewan location. (Although not shown, the maximum and minimum concentrations (i.e. upwind or downwind) vary by about a factor of 10 for the mid-latitude location.)

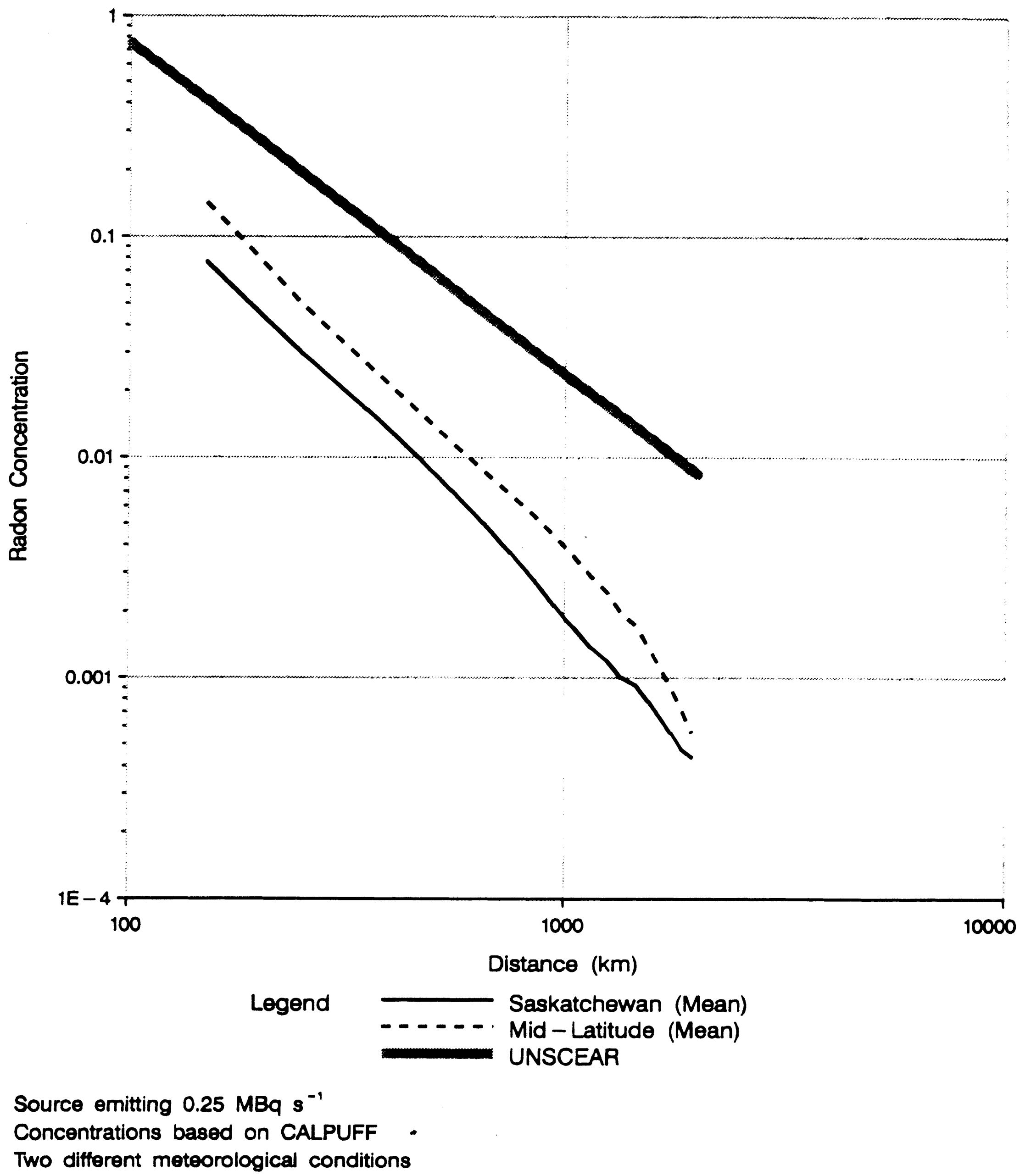

FIG.2. Predicted radon concentrtions (mBq^{-3}) with distance from tailings site based on two different meteorological conditions.

Reference concentrations

Concentrations for the sites examined in this study were estimated based on the 1 to 100 km mean concentrations estimated using for northern latitude (Saskatchewan) meteorology, and the 100 to 2,000 km mean concentrations using the mid-latitude (Mexico) meteorology. Concentrations were prorated by the ratio of site-specific emission rates to the reference case emission rate, 0.25 MBq s^{-1}, used in the dispersion modelling described previously.

The dispersion factors, and hence concentrations, used by UNSCEAR and those derived in this study for the northern Saskatchewan region differ by factors of 2 to 3 in the <100 km region. However, the differences increase with distance, with the difference being up to a factor of about 17 (UNSCEAR concentrations larger) at 2,000 km. This may be due in part to the effect of radon decay that was accounted for in this study and which reduces concentrations by about a factor of 5 at 2,000 km.

5. POPULATION DOSE ESTIMATES

Population exposure estimates were based on multiplying the population size in an area by the average radon concentration in the area. This section describes the population exposure estimates for each mining area that were estimated by multiplying the average (area-weighted) site-specific concentration in the <100 km and 100 to 2,000 km regions by the site-specific uniform population density in the regions.

Since concentrations decrease rapidly with distance, the true distribution of population within the area can significantly impact the population exposure. In order to examine the potential impacts of using a uniform rather than a true population distribution, population exposure estimates by distance from the source were investigated in detail for the northern Saskatchewan site. Site specific population distributions were not available for the other sites. In this situation, population exposure estimates were found to be about a factor of 3 to 4 lower if the true population distribution with distance were used as compared to the assumption of uniform population density within the two regions, i.e. the <100 km and about 3 times lower for the 100 to 2,000 km regions.

The long term (10,000 y) population dose estimates for the uranium tailings sites examined in this study are summarized in Table V. The normalized estimates range from 0 to 5.9 person–Sv per GW y, with an overall 1997 production-weighted average of 0.96 person-Sv per GW y. These estimates may be compared to the UNSCEAR central estimate of 150 person–Sv per GW y. The way in which the estimates for each site were derived is described in SENES [2].

TABLE V. MISSIONS FROM URANIUM TAILINGS SITES

Country	Mill Location/Name	Production Rate–1997[1] (t U y^{-1})	Normalized Population Dose (person–Sv per GW y)[2]
Australia	Ranger	4,095	0
	Olympic Dam	1,425	0.12
Canada	Key Lake	5,433	0
	Rabbit Lake	4,632	0
	Cluff Lake	1,950	2.7
Namibia	Rössing	2,905	5.9
Niger	Akouta	2,100	0.078
	Arlit	***1,350***	***0.10***
		23,890	0.96[3]

1. From [2].
2. Normalized to estimated lifetime production and 210 t U per GW y (see text).
3. 1997 production–weighted average.

Background doses

People living around the eight sites examined in this study will be exposed to background radon, irrespective of the operation of uranium production facilities. For the total of 2.11 x 10^8 people around the sites (counting only one each of the relatively close sites in Canada and Niger, and Ranger in Australia in order not to double count people), the total background dose is given by:

$$14.4\ Bq\ m^{-3} \times (2.11 \times 10^{8}) \times (6.4 \times 10^{-9}\ Sv\ h^{-1})(Bq\ m^{-3})^{-1} \times 8.76 \times 10^{3}\ h\ y^{-1} \times 10^{4}\ y$$

$$= 1.7 \times 10^{9}\ person - Sv$$

The assumed 14.4 Bq m^{-3} (EEC, equilibrium equivalent concentration) average background radon concentration was derived from UNSCEAR [1] as follows. The previously noted Section 4) outdoor concentration of 10,000 mBq m^{-3} (10 Bq m^{-3}) converts to 8 Bq m^{-3} (EEC) based on an outdoor radon progeny equilibrium factor of 0.8. The indoor concentration of 40 Bq m^{-3} converts to 16 Bq m^{-3} (EEC) based on an indoor equilibrium factor of 0.4 [1, p. 54]. For 80% indoor occupancy and 20% outdoor occupancy, these concentrations give an overall average of 14.4 Bq m^{-3} (EEC).

This is probably a conservative (low) dose estimate because background concentrations in areas with uranium deposits are generally higher than typical background levels. The dose of 1.7×10^9 person-Sv per 10^4 y is a factor of 366,000 larger than the total population dose of 4,650 person–Sv for all the sites examined in this study. These results are discussed in more detail in the next chapter.

6. DISCUSSION

6.1. Comparison of UNSCEAR population dose estimate with estimates from this study [2]

In this study, the long term (10,000 y) population doses due to radon emitted from uranium tailings areas were estimated for eight sites in four countries that currently (1997) contribute to 67% of the world's production of uranium. (As noted in Section 1 relative to *in situ* leach facilities, the results of this study could be considered to represent the impacts of long term radon emissions based on 80% of current uranium production). The estimates were based as much as possible on site-specific information. The radon emission rates used were considered to be applicable to the sites when eventually closed down and decommissioned. Because of study constraints relative to the acquisition of meteorological data for every site, an air dispersion model based on two sets of meteorological data from a previous study was used for all the sites.

The overall, normalized population dose estimate of 0.96 person-Sv per GW y of electrical energy produced is about a factor of 150 lower than UNSCEAR's [1] estimate of 150 person-Sv per GW y. The more recent and site-specific information obtained for this study was not available to UNSCEAR, who had to rely on generic radon emission and population data for their estimates.

UNSCEAR [1] provided a range of 1 to 1,000 person-Sv per GW y about their central estimate of 150 person-Sv per GW y. The central estimates for every site examined in this study were below the UNSCEAR central estimate, while the central estimates for six of the sites were below UNSCEAR's suggested bottom range estimate of 1 person-Sv per GW y. Some of the more significant parameters that contribute to these differences in the estimates are discussed below.

Radon emission rates

Based on the information summarized in Table III, the long term emission rate of radon from tailings used by UNSCEAR substantially exceeds the rates expected for the most of the tailings sites examined in this study. While the value of the long term emission rate at any site is certainly speculative (especially to 10,000 y), it is clear that the UNSCEAR's central estimate did not account for the current and short term future tailings management practices that would essentially eliminate radon emissions at some sites i.e. saturated, water-covered tailings. The lower estimate of 1 person-Sv per GW y given by UNSCEAR does indicate that UNSCEAR acknowledges the uncertainty in their estimate (and specifically that their estimate may be too large), although the numerical basis for their estimated range is not given by UNSCEAR.

Normalized emanating area of tailings

The UNSCEAR estimate of 1 ha per GW y differs from (overestimates) the surface area of tailings based on more recent data, or conversely, underestimates the thickness of tailings, and correspondingly the amount of potential electrical energy, associated with the radon emissions. This increases the final estimate of person-Sv per GW y, especially for the deeper (thicker) tailings areas. Deeply buried tailings essentially contribute zero radon to the environment but the ore associated with those tailings does result in the production of electrical power.

Population density

The overall population densities assumed by UNSCEAR for their modelled tailings site typically overestimate the current population densities at the sites examined in this study. Data collected for this study shows that for the <100 km region, the ratios of the UNSCEAR estimate of 3 persons km^2 to the site-specific densities range from 0.9 to 88.2. The ratios for the 100–2,000 km region range from 3.5 to 16.7, whereas the UNSCEAR estimate is 25 persons km^{-2}.

This study also examined the effects of using uniform, rather than actual population distributions as a function of distance around a tailings site. For the Saskatchewan site, for which data were available to this study, the assumption of uniform (i.e. two region) distributions overestimates the cumulative population dose for the by about a factor of 2.5. While this difference (the factor of 2.5) is not necessarily applicable to other sites, the analysis indicates the magnitude of one of the sources of uncertainty associated with the final dose estimates.

Air dispersion factors

As done in this study, UNSCEAR makes use of generic air dispersion factors in assessing the dispersion of radon released from the decommissioned tailings. The air dispersion factors derived in this study compare within a factor of about 3 with the UNSCEAR factors at distances <100 km, but diverge from the UNSCEAR factors, by factors of 4 to 10 and more, in the 100–2000 km region. The analyses carried out in this study suggests that only part of this difference in the distant region is due to site-specific parameters, since the direction-averaged dispersion factors for the northern latitude (Saskatchewan, Canada) and mid-latitude sites (Mexico) differed by less than a factor of two. Not accounting for radon decay with distance also appears to have contributed to UNSCEAR's higher estimate (relative to this study) of the air dispersion factors. If radon decay were to be included in the UNSCEAR values, the air dispersion factors derived in this study would be within about a factor of three of the UNSCEAR values.

6.2. Uncertainties

Similar to the UNSCEAR long term population dose estimates, the estimates derived in this study are inherently uncertain. Some of the sources of this uncertainty are qualitatively discussed below.

Representativeness of the sites examined in this study

The eight sites examined in this study are currently (1997) responsible for 67% of the world's production of uranium. (As previously noted, the results of this study could be considered to represent the impacts of long term radon emissions based on 80% of current worldwide uranium production if *in situ* leach facilities are considered). The conditions at other production facilities may be significantly different than today's major producers, in terms of population densities and especially in terms of overall radon emission rates per unit of potential electrical energy produced. The overall population dose for all existing facilities may therefore be different.

However, given that tailings management practices are continually evolving and that the sites examined here may be considered representative of likely future practices, the estimate derived in this study is probably a fair representation of conditions in the foreseeable future.

Future fuel cycles

The population dose estimates from both this study and UNSCEAR were based on assumed uranium fuel requirements of 210 t U per GW y. Future fuel cycles, including reprocessing, could significantly lower fuel requirements and would correspondingly result in lower population doses per GW y due to radon emissions from uranium tailings.

Population growth

The population dose estimates were based on current (generally within 10 years) population densities. There is the potential for long term population growth but the rate and numbers over the very long term (10,000 y) is unknown. On a worldwide basis, and considering the finiteness of earth's resources, the long term population is unlikely to be more than a factor of five to ten larger than today's population.

On the other hand, in <100 km region, because many of the uranium producing facilities are in remote locations, the local populations may well decrease once those facilities are no longer operating.

All this is clearly speculative but the uncertainties due to population growth affect both the estimates derived in this study and the UNSCEAR estimate. The estimated population doses from background radiation would also be affected by population growth.

Population distribution

As discussed in Section 5, the assumption of uniform (two region) population densities resulted in nearly a threefold overestimation of population dose for the northern-latitude site, based on the actual population distribution. A similar or greater magnitude of overestimation or underestimation could exist at any site. The location of the population relative to wind direction causes larger uncertainties, by factors of 5 to 15 when comparing maximum (downwind) and minimum (upwind) population doses. These uncertainties are equally inherent in the UNSCEAR estimate of population dose.

Air dispersion factors

Air dispersion characteristics, especially near-field, can be very site-specific. However, except for sites that might have population centres located generally downwind of the site in the <100 km region, the largest population dose will occur to people living in the 100–2000 km region. The air dispersion factors estimated in this study for both a northern and mid-latitude site were comparable (within a factor of two), but smaller than the UNSCEAR dispersion factors. If radon decay (up to a factor of about 5 at 2000 km) were included in the UNSCEAR dispersion factors, the latter would also be comparable (within a factor of about three) to the dispersion factors used in this study.

Overall uncertainty

The major objective of this study was to estimate the normalized (to unit of power produced) long term population dose due to radon emitted uranium tailings, using the same methodology as UNSCEAR but based on more site-specific information. A quantitative uncertainty analysis of the results was beyond the scope of work for the study. However, the following qualitative comments are offered.

The contribution to the overall uncertainty due to imprecision in the site-specific information (overall radon emission rate, population densities and the potential amount of uranium associated with the tailings) is likely to be much smaller than from the uncertainty in other factors that affect the estimation of population dose. Considering the uncertainties in population distributions within each region (<100 km and 100–2,000 km), meteorological dispersion, the air dispersion model and overall population growth, the overall uncertainty range for sites with specific information is subjectively estimated at about a factor of ten about the central estimate.

A reliable estimate of the population dose for sites not considered in this study (corresponding to about one-fifth of current world production) cannot be made at present because their site-specific conditions (radon emissions, population densities, etc.) were not available.

6.3. Other issues

Perspective on estimated population exposures and doses

Notwithstanding the uncertainties associated with the analyses undertaken here, it is perhaps informative in terms of perspective to examine the magnitude of the estimated radon exposures and doses.

The total long term (10,000 y) population dose to radon emissions from the uranium tailings sites examined in this study is about 4,650 person-Sv (Section 5). Using ICRP's [19] nominal probability coefficient of 0.06 total cancers per person-Sv, this population dose converts to about 280 cancers over 10,000 years or less than 3 cancers over a typical lifetime. This may be compared to the more than 60 million background cancers expected in the lifetime of the approximately 210 million people living within 2,000 km of the sites (assuming a 30% background cancer incidence rate). The 4,650 person-Sv estimate is a factor of 366,000 below the background population dose of 1.7 x 10^9 person-Sv for the same sites.

The area-weighted concentrations in the <100 km region are factors of 200 or more lower than background concentrations. A large fraction (3,720 person–Sv or 80%) of the population dose is incurred by people living beyond 100 km of the sites. The area-weighted average radon concentrations in the 100–2000 km region around the sites are estimated to range from near zero to about 0.2 mBq m^{-3}. These concentrations are factors of more than 50,000 lower than typical outdoor background concentrations.

Linear, no threshold dose response model

The population doses estimated in this study and by UNSCEAR implicitly assume the validity of the linear, no threshold (LNT) dose response model; that is, the risks of exposure to radiation are assumed to be directly proportional to the dose received, down to zero dose. There is much current discussion of the appropriateness of the LNT model for estimating impacts from doses that are extremely small fractions of natural background radiation. The presence of a dose threshold, even a practical threshold in which competing causes of death defer the risk from radiation beyond the expected lifespan for detrimental effects, or of a hormetic effect would render any assumed impacts associated with the population doses estimated in this study or by UNSCEAR invalid.

Integration period

To be comparable to the UNSCEAR estimate, the population doses estimated in this study were integrated over a 10,000 year exposure period. While UNSCEAR chose this period for illustrative purposes, the assumption that conditions for which the dose estimates were derived would be constant over this period is clearly speculative.

However, it is quite likely that total or at least partial cures for some of the potential cancers associated with radiation exposure would have become available in the 10,000 y time period. On this basis, notwithstanding the issues associated with the LNT model noted previously, or from future improvements in medical care of cancer, it is likely the any impacts associated with the population doses derived in this study or by UNSCEAR will be overestimates of the actual (if any) impacts.

7. CONCLUSIONS

The major conclusions from the present study are:

- Based on the site-specific data available to this study, UNSCEAR's generic estimate of radon emissions from uranium tailings sites is too large for the sites examined in this study.

- Relative to the assumption of uniform (two region) population densities, the use of site-specific population distributions can result in significantly different (larger or smaller) population dose estimates.
- The radon concentrations associated with the tailings emissions are extremely small on both a relative (compared to typical background levels) and absolute (in terms of dose and risk) level. In the authors view the individual risk of cancer associated with the predicted concentrations is below a level that can be considered completely insignificant and trivial, i.e. *de minimis.*
- The uncertainties in the estimates provided in this study were reduced relative to the uncertainty in the UNSCEAR estimate because of the availability of more site-specific data on radon emissions and population densities. Further refinement of the analyses would require the use of site-specific meteorological data and population distributions.
- UNSCEAR's central estimate of the long term (10,000 y) population dose due to radon emissions from uranium mill tailings is too large, by about a factor of 150, based on site-specific data and current and proposed tailings management practices at the sites examined in this study.

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RECOMMENDATIONS FOR A COORDINATED APPROACH TO REGULATING THE URANIUM RECOVERY INDUSTRY

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Executive Summary

A number of regulatory positions that are of central importance to the uranium recovery industry today have their origins in regulatory interpretations that were developed by Nuclear Regulatory Commission (NRC or Commission) staff almost two decades ago, shortly after Congress first granted the Commission the direct authority to regulate uranium mill tailings and related wastes by enacting the Uranium Mill Tailings Radiation Control Act (UMTRCA) as an amendment to the Atomic Energy Act of 1954 (AEA). Consequently, several key regulatory positions that govern uranium recovery activities today were developed at a time when the regulatory programme for uranium milling operations, including the management and disposition of uranium mill tailings and related wastes, was in the earliest stages of conception, and when the uranium recovery industry was at or near peak levels of production. Often, the policies and positions that were developed by the Commission staff dining this period, and subsequently, were developed in an *ad hoc* manner, rather than being formulated as part of a deliberate, coordinated regulatory strategy. Moreover, many of these positions and policies were based on assumptions that would later turn out to be completely incorrect regarding the future development of the uranium recovery industry and of the regulatory programme governing the industry.

In the twenty years that have elapsed since Congress first enacted UMTRCA, a robust programme has been created for the comprehensive regulation of uranium recovery activities. At the same time, the nature of the uranium recovery industry has changed dramatically. As a result, some of the policies and positions that were developed by Commission staff almost two decades ago, that may have seemed reasonable at the time they were developed, appear increasingly unreasonable and inappropriate today, given the current regulatory framework and the realities of the modern uranium recovery industry. This raises concerns about the effectiveness of the current regulatory system at controlling uranium mill tailings and related wastes in a manner that optimizes protection of public health, safety and the environment. In addition, the patchwork of sometimes outdated and sometimes erroneous policies and positions that have been developed over the past 20 years has led to increasing confusion within the uranium recovery industry, which has been exacerbated by the inconsistent and sometimes ill–considered manner in which NRC staff have, in some of their policies and positions, deviated from the definitions of key terms set out in the statute and the relevant regulations. These terms, particularly “source material” and “byproduct material”, have jurisdictional significance for NRC and for uranium recovery licensees. While the Commission certainly has flexibility in interpreting these statutory terms, it must do so in a way that is carefully thought out and legally supportable, and in a way that does not jeopardize the consistent implementation of the overall regulatory programme created in the AEA, as amended by UMTRCA.

In this White Paper, NMA examines several of the more important policies and positions that have been adopted by NRC staff over the past two decades pertaining to uranium recovery activities. Through this examination, NMA hopes to provide the Commission with a fresh perspective on the implications that these staff policies and positions carry for regulatory policy under the AEA in general, and for the uranium recovery industry in particular. The White Paper focuses on staff policies and positions in the following areas: (i) the concurrent jurisdiction of non–Agreement states to regulate *non–radiological* aspects of 11e.(2) byproduct material; (ii) NRC's jurisdiction over in–situ leach (ISL) uranium recovery facilities; (iii) the disposal of *non–11e.(2) byproduct material* in uranium mill tailings piles; and (iv) NRC's alternate feed policy. It is NMA's hope that the fresh perspective offered by this White Paper will provide the Commission with a useful framework for realigning some of the staff policies governing uranium recovery activities in a manner that optimizes the net benefit to public health, safety and the environment.

1. JURISDICTION OF NON–AGREEMENT STATES OVER THE NON–RADIOLOGICAL ASPECTS OF 11.E(2) BYPRODUCT MATERIAL

In 1980, NRC's Office of Executive Legal Director (OELD) issued an advisory legal opinion concluding that federal law does not preempt the exercise of non–Agreement state authority over the non–radiological aspects of 11e.(2) byproduct material. In reaching this conclusion, OELD conceded that "*the question is so close that the Commission could reasonably choose either interpretation".* Thus, even at the time the opinion was issued, OELD believed that the arguments favoring federal preemption of non–Agreement state regulation were persuasive. However, in the end, the legal staff chose to support the opposite position, concluding that non–Agreement states can exercise concurrent jurisdiction over the non–radiological aspects of 11e.(2) byproduct material.

NMA believes that the arguments adduced by OELD in support of preemption were clearly more persuasive than the arguments offered by OELD favoring concurrent jurisdiction. Moreover, it appears that OELD failed to consider several arguments in addition to those set forth in its memorandum, that would have further buttressed a finding of preemption. Thus, it is evident that the correct legal interpretation in 1980, and indeed the only permissible interpretation, would have found non–Agreement state regulation of *all* 11e.(2) byproduct material completely preempted. The argument favoring total preemption of non–Agreement state authority with respect to 11e.(2) material becomes overwhelming when viewed through the lens of today's regulatory environment. Indeed, when viewed through this lens, it becomes clear that the federal scheme set out in UMTRCA for regulating uranium mill tailings and related wastes satisfies two separate tests established by the Supreme Court, either one of which, alone, would be sufficient to demonstrate preemption.

First, the AEA, as amended by UMTRCA, establishes *a pervasive federal scheme* for the regulation of uranium mill tailings and related wastes. No less than three federal agencies play an active role in regulating mill tailings. Pursuant to section 274 of UMTRCA, the U.S. Environmental Protection Agency (EPA) has issued detailed, generally applicable standards to address *both* radiological and *non–radiological* hazards (i.e., groundwater) associated with mill tailings that are closely modeled after its Resource Conservation and Recovery Act (RCRA) regulations. In turn, NRC has incorporated these regulations into its criteria for the management and closure of mill tailings sites, set forth at 10 C.F.R. Part 40, Appendix A. In addition, NRC plays the key role in overseeing closure of active uranium mill tailings sites and final disposal of the tailings themselves. Finally, the Department of Energy (DOE) completes the circle of federal oversight of uranium mill tailings by acting as the permanent custodian and perpetual licensee of sites used for the disposal of tailings under Title II of UMTRCA, as well as exercising primary responsibility for selecting and overseeing the remediation of inactive uranium mill tailings sites under Title I of UMTRCA.

The OELD opinion was issued at a time when the federal regulatory regime governing uranium mill tailings and related wastes was in its infancy. At that time, the roles that the EPA, NRC and DOE were assigned under UMTRCA in implementing the statutory scheme had not been elaborated upon in regulations. In addition, it appeared at the time that the radiological hazards (i.e., radon emissions) associated with those tailings and wastes would be the primary focus of regulatory concern. Indeed, OELD cited this apparent focus on radiological hazards as supporting the conclusion that federal regulation of mill tailings preempted non–Agreement state regulation *only* with respect to the *radiological* aspects of 11e.(2) material. However, in the nearly twenty years since the OELD opinion was written, the regulatory scheme set out in UMTRCA has developed into a robust and comprehensive federal programme that regulates both radiological and *non–radiological* components of mill tailings and related wastes – from the point of their generation through to their ultimate disposition. The pervasiveness of this federal scheme indicates that Congress did not intend to allow non–Agreement states to exercise concurrent jurisdiction over *either* the radiological or the *non–radiological* aspects of 11e.(2) byproduct material.

Second, the exercise of concurrent jurisdiction over 11e.(2) byproduct material conflicts with federal law, because it is inconsistent with the overall statutory scheme created by the AEA, as amended by UMTRCA, and it frustrates Congress' purpose in enacting UMTRCA. This inconsistency is most evident in the impact of concurrent jurisdiction on the Agreement state programme. While Agreement states must carefully conform their regulation of radiological and *non–radiological* hazards associated with 11e.(2) material to federal standards, as required by section 274(o) of UMTRCA, non–Agreement states would be free to regulate 11e.(2) material without any regard to consistency with the federal standards. In other words, Agreement states would have to comply with stringent requirements in order to achieve and retain their Agreement state status in order to receive *less* authority (at least with respect to 11e.(2) byproduct material) than they would otherwise be able to exercise as non–Agreement states. Such a result turns the Agreement state programme, as set out in the statute, on its head.

Similarly, the exercise of concurrent jurisdiction by non–Agreement states would conflict with the role established for NRC under section 84 of the AEA, which directs the Commission to *"insure"* that the management of *any* 11e.(2) byproduct material is carried out in a manner that:

(1) the Commission deems appropriate to protect the public health and safety and the environment from radiological and non–radiological hazards associated with the processing and with the possession and transfer of such material, taking into account the risk to the public health, safety, and the environment, with due consideration of economic costs and such other factors as the Commission determines appropriate.

If non–Agreement states were allowed to exercise concurrent jurisdiction over *non–radiological* aspects of 11e. (2) byproduct material, then non–Agreement states could force licensees to perform virtually any remedial action, beyond those required by NRC, regardless of the net risk, cost, or environmental impact and conceivably even after termination of the license granted by NRC. Under this policy, the Commission would be unable to weigh the impacts of state imposed actions with the other factors mandated for consideration by the Statute, thereby leading to inappropriate management of 11e.(2) byproduct material, in contravention of Section 84 of the AEA.

The exercise of concurrent jurisdiction would also interfere with license termination and site closure at Title II sites. After operating for many years under federal standards governing non–radiological hazards and having had corrective actions approved based upon those standards, a facility may have to comply with additional requirements imposed by the state as a condition of site closure. This would not only substantially increase closure costs but also delay license termination, particularly in instances where the state imposed requirements are technologically or economically infeasible for a licensee to comply with, since NRC and DOE have recently signed a protocol whereby the Commission will not terminate the license of and DOE will not accept custody to any mill tailings site that has not resolved "*all* issues with state regulatory agencies". Similarly, if non–Agreement states are allowed to exercise concurrent jurisdiction, and to impose whatever remediation requirements they deem necessary in order to address non–radiological concerns associated with 11e.(2) byproduct material, DOE may find it impossible to accept title to uranium mill tailings disposal sites in such states, even following completion of all remedial actions required by NRC, because of concerns that the state might, at some point in the future, impose additional remediation requirements beyond those contemplated by NRC. In particular, DOE may refrain from taking title to such sites because of the possibility that the additional regulatory burdens imposed by the non–Agreement state, and the economic costs associated with those regulatory burdens, would conflict with the directive continued in Section 83 of the AEA, which requires that the transfer of title to DOE occur *without cost to the government* other than administrative and legal costs associated with the transfer itself. This reluctance in the part of DOE is likely to be compounded by the federal facilities compliance Act, which waives sovereign immunity with respect to Federal Facilities Compliance with state laws respecting the control of hazardous waste disposal and management.

If concurrent jurisdiction were to be permitted, the result would be the sub–optimization of protection of public health and safety and the environment, which, in the extreme, could preclude site closure and/or increase site-specific adverse impacts associated with closure activities. By impeding site closure, the exercise of concurrent jurisdiction by non–Agreement states frustrates one of the primary goals underlying UMTRCA–orderly closure and remediation of mill tailings sites. This disruptive effect is greatly amplified by the large number of sites currently preparing for closure.

In view of the compelling arguments supporting federal preemption and the potentially grave consequences of allowing concurrent jurisdiction, the Commission should discard the current *de facto* staff policy as contrary to law and not optimally protective of public health and recognize complete federal preemption in the regulation of 11e.(2) byproduct material.

2. JURISDICTION OVER IN–SITU LEACH OPERATIONS

NRC's assertion of jurisdiction over the underground portions of ISL wellfields raises similar issues and concerns. For example, in 1980 NRC legal staff prepared a memorandum which concluded that the AEA provides NRC with jurisdiction over the subsurface aspect of ISL wellfields. This advisory legal opinion was prepared at a time when the regulatory programme for the uranium industry was still developing and ISL was still a relatively new technology that comprised a fairly insubstantial portion of the uranium recovery industry. Thus, in its advisory opinion, NRC legal staff was, in effect, trying to predict how the new jurisdiction over 11e.(2) material granted to the Commission under UMTRCA would relate to ISL operations. With the best of intentions, OELD made the erroneous determination that NRC had authority over the subsurface aspects of ISL activities.

The fundamental problem is that NRC's legal staff reached its erroneous conclusion as a result of a misapplication of the statutory definitions by which Congress provided the Commission with jurisdiction over specific radioactive materials: source, special nuclear, and byproduct material. If a substance does not fall within the scope of one of these definitions, then the AEA does not provide NRC with authority to regulate it. Accordingly, the statutory definitions must be applied to each material over which NRC claims regulatory jurisdiction. Although these definitions need not be applied inflexibly, they should be applied consistently and the applications should be legally supportable. This approach, if applied to ISL wellfields, will show that because the underground activities do not involve materials within the AEA's statutory definitions, NRC has no jurisdiction over these subsurface activities. Moreover, the legal staff's attempt to support its conclusion by claiming that the National Environmental Policy Act (NEPA) provides a *"supplemental"* grant of jurisdiction suggests a well–intentioned, but erroneous, reading of that act and the cases applying it. Although early federal cases were less than clear on the issue, contemporary NEPA decisions hold that the statute provides no supplemental jurisdiction beyond an agency's organic act.

Additionally, when it drafted the 1980 memorandum asserting jurisdiction over ISL wellfields, the legal staff did not have the perspective we have today as the industry is in its maturity. Without this perspective, the legal staff did not foresee the contradictions and inconsistencies that would become evident as NRC staff scrambled to make their jurisdictional claim over subsurface activities make sense. As just one example, in 1980 the legal staff did not have reason to predict the practical difficulties associated with liquid effluent discharges at ISL facilities when, applying the legal staff's approach, mining wastes and byproduct materials are commingled in storage ponds. NRC's reaction to this situation, and its reaction to other contradictions and concerns in the ISL context, have implications that reach beyond the ISL sector and that may even present obstacles to final closure of mill tailings piles.

Similarly, in 1980 NRC legal staff did not know that EPA's underground injection control (UIC) programme would provide such comprehensive protection over the subsurface aspect of ISL mining. That programme now requires any ISL project to undergo an EPA permitting process to ensure that no underground sources of drinking water are affected. To receive EPA approval, the ISL facility must meet specific UIC regulations and standards for constructing and operating the wellfield. Therefore, NRC regulation of the underground portion of the wellfield is duplicative and could be viewed as a waste of federal resources.

Finally, the legal staff's eagerness to assert jurisdiction over underground activities at ISL wellfields is perplexing when contrasted with its restraint in the concurrent jurisdiction context. As noted above, the legal staff suggested that despite the overwhelming federal interest and presence in the mill tailings programme, non–Agreement states might have concurrent jurisdiction over non–radiological hazards at tailings piles. Accordingly, NRC has not asserted exclusive jurisdiction over these hazards in non–Agreement states. On the other hand, the legal staff claims that Congress provided the authority to regulate ISL mining activities that are outside the scope of AEA jurisdiction. This is despite the absence of any indication that Congress was concerned with the subsurface activities at ISL wellfields and despite a lack of any significant federal presence in the ISL uranium recovery industry. Indeed, at the time Congress enacted UMTRCA, non-conventional methods of uranium mining such as ISL were not expected to produce significant quantities of uranium.

3. GUIDANCE ON DISPOSAL OF NON–11e.(2) BYPRODUCT MATERIAL

Under NRC's final guidance for disposal of non–11e.(2) *byproduct material* in tailings piles, a facility may dispose of *non–11e.(2) byproduct material* in tailings impoundments only after satisfying nine criteria specified in the guidance. NRC's purpose in establishing these criteria is to prevent inappropriate commingling of mill tailings with non–11e.(2) *material* in tailings piles in order to prevent "contamination" of the tailings and thus to avoid any duplicative regulation by EPA or a state. Ultimately, the *non–11e.(2) policy* is intended to facilitate eventual transfer of the tailings to DOE or a state upon license termination. However, the current guidance imposes a tremendous burden on facilities wishing to dispose of non–11e.(2) byproduct material directly into tailings piles and, as such, is inconsistent with sound public policy and with the goal of optimizing protection of public health, safety and the environment, and thus needs to be revised to facilitate such practices.

As with the other staff regulatory interpretations examined in this White Paper, there are sound legal and policy reasons for addressing this issue as part of a comprehensive overview of NRC's regulatory programme for uranium recovery facilities. For example, there are many materials that do not meet the definition of 11e.(2) byproduct material but that have almost the identical radiological and toxicological characteristics. Given the shortage of disposal capacity for low level radioactive materials, the difficulties associated with siting new disposal facilities, and the conservative UMTRCA requirements that protect public health and the environment, it makes a great deal of sense to allow the disposal of these *non–11e.(2) materials* in tailings piles.

While DOE is only required by UMTRCA to take 11e.(2) byproduct material, Section 151(b) of the Nuclear Waste Policy Act (NWPA) allows DOE to take title to and custody of low level waste under certain conditions that UMTRCA and the regulations thereunder satisfy *by definition*. Moreover, to the extent that there are any concerns about whether DOE or a state will take title to a tailings pile, these issues easily can be resolved through an interagency agreement or Memorandum of Understanding.

UMTRCA does not preclude the disposal of *non–11e.(2) materials* in tailings piles. Rather, the flexibility in that act and sound policy considerations suggest that the Commission should consider how mill tailings piles can most effectively be used to provide a safe and economically viable disposal option for some low level radioactive materials that are *similar* physically, chemically, and radioactively to 11e.(2) byproduct material.

4. ALTERNATE FEED POLICY

In 1995, NRC issued its policy for processing of uranium mill feed material other than natural ores in response to various requests it had received in prior years to process feed material other than natural uranium ore at uranium mills, some of which the Commission had approved. Examples of typical alternate feed include wastes from other mineral recovery operations (i.e., niobium–tantalum extraction) and mine dewatering that contain uranium. The policy imposes three requirements for acceptance of alternate feed: (1) the material must qualify as "ore," as that term is regulatorily defined; (2) the material must not contain any listed hazardous waste; and (3) the material must be processed "primarily" for its source material content, as demonstrated by either the co–disposal test or the certification test[1]. These requirements reflect the Commission's, concern that tailings and other wastes generated by processing of alternate feed qualify as 11e.(2) byproduct material so that the transfer of custody to mill tailings impoundment upon license termination to DOE will proceed without complications.

However, the policy, in its current form, restricts rather than facilitates the use of alternate feed material at uranium mills. The Commission should modify the policy to maximize the processing of alternate feed since such use produces two substantial benefits – extraction of valuable source material and utilization of waste disposal capacity of mill tailings sites. Such benefits also greatly outweigh any concerns about "sham disposal", which is a classic "red herring" that should be dismissed as a policy concern. *Non-11e. (2) byproduct material* that would otherwise have to be disposed of at substantial cost may be processed as feed material for its source material value and to create 11e. (2) byproduct material, thus assuring its long term isolation to protect against any adverse impacts to human health or the environment. It is hard to imagine a more sound public policy at a time when LLRW disposal capacity is expensive and ever more limited.

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[1] Under the co-disposal test, a licensee must meet all nine criteria of the current policy for disposal of *non-11e.(2) byproduct material*. Meeting these criteria would demonstrate that the facility was processing the feed material for its source material content rather than engaging in "sham disposal" of low level radioactive waste (LLRW) that would otherwise have to be disposed of at LLRW waste facilities at far higher cost. In other words, if the material could go directly into the tailings pile, the reason for its processing must be for its source material content. Under the certification test, a licensee must certify that it is processing the feed material for its source material content and appropriately justify such a certification.

REGULATORY IMPACTS ON THE CANADIAN URANIUM INDUSTRY

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Abstract

The development of environmental and safety regulation in Canada is described and the impacts of these developments on various phases of the uranium industry are examined. In the past 25 years, seven new uranium mining projects, major expansions to four projects, and five uranium refining/conversion projects have undergone environmental assessment in Canada. As regulations and the processes for applying them have developed, the size, complexity and cost of obtaining operating approvals for uranium projects have increased exponentially. Uranium projects are subject to a level of scrutiny that goes far beyond what can be justified by their potential for environmental damage, based primarily on a perceived degree of public concern, rather than any objective measure of environmental risk. The author believes that it is time to re-examine our priorities, to establish some balance between the risks of a project and the assessment effort required. Otherwise, we shall soon find ourselves in the position where smaller projects will never be developed because they cannot cover the regulatory costs.

1. INTRODUCTION

The Canadian uranium industry moved from rapid expansion in the 1950s into a ten-year slump in the early 1960s. The rising demand for uranium and the resultant increase in price in the early 1970s sparked a new wave of exploration which bore fruit in an unprecedented expansion of the industry. The Rabbit Lake mine started production in 1975. Rio Algom and Denison started major expansions at Elliot Lake in the late 1970s. New mines at Cluff Lake and Key Lake started up in the early 1980s. The 1990s have seen new mines at McClean Lake, the Midwest Project at South McMahon Lake, Cigar Lake and McArthur River, together with new developments at the existing Cluff Lake and Rabbit Lake mines. In uranium refining and conversion, five new projects were subjected to environmental assessment between 1975 and 1980, resulting in two new plants being built. At the same time that these projects were under development, the regulations which control them were undergoing major changes.

2. CANADIAN REGULATORY REGIME

Canada has a federal government and ten provincial and two territorial governments. Resource development has always been a provincial matter and is normally conducted under provincial laws. However, the development of atomic energy was made a federal matter by passage of the Atomic Energy Control Act in 1946, and all matters related to the development of atomic energy, including all facets of the uranium industry are regulated by the Atomic Energy Control Board (AECB), a federal agency. The involvement of provincial governments in the uranium industry has been largely a matter of choice by the provincial governments. Saskatchewan, which is the source of all uranium now being mined in Canada, has chosen to exert control over uranium mining and does so by surface lease agreements. Since all the mining is taking place on provincial lands, the mining company must sign a lease with the province. The province inserts clauses into the lease agreement, which commit the company to abiding by provincial law and any additional provisions that the province may see fit to add. In Ontario, the other (former) uranium producing province, the provincial government has varied in its direct interest in the uranium industry, but has applied provincial law to uranium mining operations.

The net effect of this approach to regulation has been a duplication of effort to a varying degree in a number of areas that directly affect the uranium operations. The provinces have generally been stronger in conventional mine safety and they have usually been the leaders in inspection and enforcement in this area at the uranium mines. In some cases agreements have been signed with the federal agency formally giving the province authority in the conventional health and safety area. In the environmental area, the provinces, particularly Saskatchewan, have also taken a lead, but the federal Departments of Environment and Fisheries and Oceans exert influence as advisors to the Atomic Energy Control Board. The AECB has concentrated more on the radiation protection requirements, but Saskatchewan also has a well-developed radiation protection act and regulations and enforces these through the surface lease agreements.

During the period of this review, the regulations have been evolving. The current federal radiation protection requirements are based on the pre-1977 recommendations of the International Commission on Radiological Protection (ICRP), but new regulations, based on the 1990 recommendations of the ICRP [1] are in draft and are expected to come into force in 1999. These regulations have been written under the new Nuclear Safety and Control Act, which will replace the Atomic Energy Control Act, and replace the AECB with a new agency, the Nuclear Safety Commission. The Province of Saskatchewan introduced new regulations based on ICRP Publication 60 several years ago.

The federal government first introduced environmental assessment requirements by cabinet memorandum in the early 1970s. These were initially applied only to federal government works. The requirements were formalized by a cabinet order in 1984 and applied not only to federal works but to any activities regulated by federal laws or agencies. In 1994 the federal government passed the Canadian Environmental Assessment Act, creating a federal government agency with the responsibility for environmental assessment. The regulations under the act are very detailed and broadly applicable. They cover screening of projects for potential impacts, various levels of environmental assessment, and include provisions for public hearings.

The Province of Saskatchewan passed an Environmental Assessment Act in 1979, but the government had the authority to conduct public inquiries under earlier, more general legislation that was not specific to environmental assessment. Ontario also had legislation in place in the 1970s, which permitted the conduct of public hearings into environmental matters.

3. ENVIRONMENTAL ASSESSMENT OF URANIUM PROJECTS

An environmental impact statement was developed in 1973 for the Rabbit Lake mine. It was reviewed by the Saskatchewan Environment Department, but there were no formal hearings and little public attention. Mining started in 1974 with the first uranium production in 1975.

The Cluff Lake project had identified a number of ore bodies, but the first, the D ore body, was the highest-grade uranium ore body yet to be developed in Canada. The Saskatchewan government appointed a commission in 1977 to conduct an inquiry into the project. This inquiry was very broad-ranging, dealing with nuclear power, waste management, weapons proliferation, radiation risk and the adequacy of radiation protection requirements, and moral and ethical issues, in addition to environmental, safety and socio-economic matters. Despite the broad range of material, the commission completed its work and reported to the government in 16 months [2]. Mining started in 1980 and the first uranium concentrate was produced late that year.

At the same time in Ontario, the Environmental Assessment Board was conducting hearings into the proposed expansion of the Elliot Lake uranium mines operated by Rio Algom and Denison. This hearing was more limited in scope, dealing primarily with environmental matters and with impacts on the Town of Elliot Lake, although there was consideration of the adequacy of standards. The board was appointed in September, 1976, and reported [3] in May, 1979 (32 months); however, it should be noted that the environmental impact statement (EIS) was developed after appointment of the board, whereas the Cluff Lake EIS had been prepared before the appointment of the commission. Production from the various expanded facilities started between 1980 and 1983, because construction work was started during the assessment process.

The Key Lake Board of Inquiry was appointed in December, 1979, after the EIS had been issued. This Board also made a more limited examination of the project, dealing with environmental and safety issues and regional socio-economic matters. The Board reported in January, 1981, after 13 months [4]. Production started in 1983.

Recognizing the growing need for uranium refining and UF_6 conversion capacity in the mid 1970s, Eldorado Nuclear developed proposals for new plants in Ontario and Saskatchewan. These projects were referred to the federal assessment process and a panel was appointed in 1976. Until that time the federal process had only required public meetings, to explain the project and answer questions, but this panel held public hearings. Prior to the appointment of the panel, a steering committee had developed guidelines for the two EISs. The Ontario hearings started in the fall of 1977 and the panel report refusing the project was issued in May, 1978 [5]. Subsequently, EISs were developed for the project on three alternative sites in Ontario, hearings were held in late 1978, and the panel issued its report in February, 1979, approving all three sites [6]. The refinery component of the expansion was eventually constructed at Blind River, Ontario, and commenced production in 1983. The EIS for the Saskatchewan plant was issued in July, 1979, the hearings were held in January, 1980, and the panel report was issued in July, 1980 [7]. Although the panel found that the environmental impact of the proposal was acceptable, they recommended a further examination of the social impacts before they could reach a conclusion on the overall acceptability of the project. The Saskatchewan project was not pursued further. However, to meet expanding UF_6 requirements, Eldorado built a new conversion plant on its existing operating site at Port Hope, Ontario. Since one of the alternative sites which had been approved by hearing was only a few miles from this site, no additional hearing was required, but public information meetings to deal with site-specific issues were held as part of the AECB licensing process.

The Rabbit Lake project presented an EIS for development of the Collins Bay B-zone mine in 1980 and went through the Saskatchewan environmental assessment process without a public hearing, although there were public information meetings. This is a ministerial option under the Environmental Assessment Act. Production from the new open pit started in 1985.

In 1987, the EIS for the next phase of development at Rabbit Lake was issued. This comprised the Collins Bay A-zone and D-zone open pits and the Eagle Point underground mine. Again the provincial process was followed, with public meetings but no hearing. In this case the Atomic Energy Control Board specifically agreed that the provincial process would satisfy federal requirements. The process took less than one year, although the EIS had taken about 18 months to develop before being issued publicly. However, the project was delayed due to the weakening uranium market and, when the proponent decided to proceed in 1991, the AECB announced that there was sufficient public concern that a federal environmental hearing would be required. The province chose not to participate, because it saw no reason to withdraw its previous approval. It took six months to appoint a panel for this assessment, the EIS was updated, hearings were held and the panel reported [8] in November, 1993, 24 months after being appointed. This hearing was also narrower in scope, dealing with environmental and safety matters and local socio-economic issues. Production from the first of the new ore bodies started in 1994.

By 1991, Cluff Lake was proposing to develop a new ore body, and new projects were proposed by the Midwest Joint Venture at South McMahon Lake, Minatco at McClean Lake, the Cigar Lake Mining Corporation, and Cameco at McArthur River. Since it had been ten years since the last provincial inquiry into uranium mining, Saskatchewan was interested in conducting a formal assessment. The Joint Federal-Provincial Panel on Uranium Mining Developments in Northern Saskatchewan was appointed in August, 1991, to review all five projects. The first three had already submitted environmental impact statements, but requests for additional information were issued by the panel.

The panel held scoping meetings in nine northern and three southern communities in Saskatchewan in early 1992 to garner public input into the assessment process, resulting in one of the most comprehensive sets of guidelines yet developed for an environmental impact statement [9]. Because the McArthur River deposit is between 500 and 600 m deep, it was necessary to sink a shaft and do detailed drilling from underground in order to design a mining method and develop other information required for the EIS. Although underground exploration did not require a full environmental assessment under either the Uranium and Thorium Mining Regulations or the various regulations under the Canadian Environmental Assessment Act, the panel felt that allowing the underground exploration to proceed without a detailed examination would harm the credibility of the main hearings. Consequently, the underground exploration was referred to the panel for review in 1992 and approved in early 1993 [10]. The shaft was sunk in late 1993 and early 1994, with underground development on one of the two approved levels.

Hearings for the first three projects proceeded in the first half of 1993. Although the panel mandate was more narrowly defined than that of the Cluff Lake Board of Inquiry, the discussion was fairly free-ranging and covered such issues as non-proliferation and nuclear power in general. The panel reported in October, 1993, approving the Cluff Lake project, refusing the Midwest proposal, and approving the McClean Lake project, but recommending a five-year delay to accumulate more information on the tailings management proposal, to improve the environmental baseline data, and to do further work on socio-economic issues [11]. EISs for a new Midwest proposal, Cigar Lake and McArthur River were issued in 1995. Hearings proceeded for Midwest in May and June, 1996, and for the latter two projects in the fall of 1996. The panel approved the McArthur River project in February, 1997 [12]. However, the Midwest and Cigar Lake proposals included milling the ore at McClean Lake and disposing of tailings in the Jeb pit, and the panel requested a further document on tailings management for all three projects. Additional information was submitted in late 1996 and early 1997. The panel held further public hearings dealing only with tailings issues in August, 1997, and approved the Midwest and Cigar Lake projects in November, 1997, together with a final report on cumulative observations on the five projects [13], nearly seven years after the process was initiated.

4. LICENSING PROCESS

The conclusions of the federal and provincial environmental assessment processes take the form of recommendations to the respective ministers of environment (and other ministers in the case of a joint referral to the assessment agency). The government or governments must then respond to the panel reports. In the cases described here, this response has generally taken two to three months and has generally accepted the panel recommendations, although the governments may add some conditions to the approval. On rare occasions they have decided not to accept a panel recommendation, but this decision must be fully explained in the government response. In the case of Saskatchewan, the provincial legislation requires that public opinion be solicited on the contents of the panel report before the Minister of Environment issues the government decision on the project. This entails a further 30-day public review period.

Having received a favourable report from the panel and a favourable response from the government, the proponent may then apply to the AECB and the provincial agencies for a construction licence for the project. The application must include the full engineering design package, including design criteria, detailed design, a hazards and operability study, and ALARA analysis (a demonstration that the design meets the objective that radiation exposures will be kept as low as reasonably achievable, economic and social considerations being taken into account). In the case of the tailings disposal system, detailed environmental pathways analysis is required with modelling extrapolated 10,000 years into the future. It must also be demonstrated that the recommendations of the environmental assessment panel have been taken into account in developing the detailed design. Because the level of detail in this package is so much greater than that required for the EIS, the assembly of the package can be very time consuming. Work on this package is generally started before the panel report is issued, to minimize the delay in licensing. Even so, the assessment of the design package by the province and AECB staff is likely to take several months. In the federal process, when all questions have been answered, the project is put before the Board. Board policy demands that all licensing issues be brought before two Board meetings with at least one meeting in between. The intent of this policy is to allow public input into the licensing decision. Because the Board does not meet every month, this can add a further two to three and one-half months to the approval schedule. As construction is nearing completion, the application for the operating licence is assembled and forwarded to the AECB. This must include general organizational structure, detailed operating procedures, methods of dealing with upset conditions, possibly some additional ALARA analysis, and a description of how the panel recommendations have been addressed in developing the operating procedures. Again, the license application must be heard at two Board meetings, which with the Board staff appraisal time is likely to take a total of six months after submission. The provincial process is more straightforward, but both licenses are necessary before construction can commence.

5. TRENDS IN CANADIAN ENVIRONMENTAL IMPACT ASSESSMENT

It becomes apparent in reviewing the history of environmental assessment in the uranium industry, that the assessment process is becoming progressively more arduous. The level of public participation has increased dramatically, from the initial public information meetings to direct public involvement at several stages of the assessment. Intervenor funding is now made available to individuals and to organizations to enable them to conduct independent studies and compile presentations for the hearings.

The guidelines for EISs have become increasingly complex. For example, the guidelines for Cigar Lake and McArthur River were drafted after input from public meetings in 12 communities, then given a 30-day public comment period before finally being issued in September, 1992. They comprised 78 single-spaced pages of issues to be dealt with by the proponents plus an additional 22 pages of information requests to government agencies. With guidelines this complex, the EISs themselves have grown by an order of magnitude and the level of effort required has grown similarly. Field work to develop the necessary information for McArthur River had actually started before the project was referred to the Federal Environmental Assessment Review Office (FEARO) and continued through the assessment process. Before these studies were complete, 17 different consulting firms were used with specialties ranging from hydrogeology, through aquatic biology, air dispersion analysis, environmental pathways analysis and radiation protection, to socio-economic impact assessment. In the 1970s, an EIS would consist of two or three volumes, numbering less than 500 pages. The McArthur River EIS occupied 15 volumes totaling 12,000 pages. After two days of information sessions for the panel, the panel issued a request for further information, which was supplied in an addendum of two volumes totaling an additional 800 pages. The topics covered in the EIS included the expected ones, such as the baseline aquatic and terrestrial environment, rare and endangered species, regional geology and mineralogy of the ore body. Because this is an extremely high-grade ore body, mining methods, radiation protection and waste management were also of prime importance. An economic assessment was required to demonstrate that there would be a net public benefit from the development. However, in addition to these topics, impacts on community health and community vitality, and cumulative impacts also had to be assessed, despite the fact that the nearest community is well over 100 km away and the nearest other development is some 50 km away. The assessment of the operation included a regional ecological risk assessment to identify those factors of greatest significance, and environmental pathways analysis to predict the impacts during operations and on potential future occupants of the area long after the operations are decommissioned.

To accommodate this increased effort in production of EISs and the increased level of public involvement, the time to complete the assessment has greatly expanded. The most efficient assessment process was probably the second assessment of the Ontario uranium refinery/conversion plant, which took just nine months from the initiation of the project to the issuance of the panel report. This included the writing of three EISs for the three alternative sites under consideration; however, these sites had been considered in a previous assessment, so most of the information was readily available in a useful format. In contrast, the McArthur River environmental assessment took six years from the initial referral to issuance of the panel report. The Phase 1 construction license took an additional six months for approval and the Phase 2 construction license was approved a further nine months later. In total, the process from initial notification of the regulatory agencies to the final construction approval took seven years and four months. Production is expected to start one year and four months later.

6. DISCUSSION

After the five projects were referred to FEARO for environmental assessment, FEARO and the province of Saskatchewan developed terms of reference and applicants were considered for the panel to conduct the hearings and assess the projects. The objective was to form a panel with the necessary expertise to assess the many different aspects of the projects, including mining engineering, occupational health and safety, the physical and biological environment, mill chemistry and northern native issues. Assembling the panel took about six months, because the panelists not only required the necessary expertise but also should have had no past connection with the uranium industry nor have expressed any views about the uranium industry.

Although in the end the various joint ventures achieved approval of the projects examined by the Joint Federal-Provincial Panel, one must question the need for such a microscopic examination of what are really relatively small mining projects. It appears that the environmental assessment process has become so detailed and so all-encompassing that only extremely rich ore bodies could afford to support the costs that this work entails.

Northern Saskatchewan is an area of some 250,000 km^2 with a population of only 35,000. There are three producing uranium mines and four others either planned or under construction. The nearest community to any of these mines is Wollaston Lake, which is 35 km from the Rabbit Lake mine. In many cases there is no road access between the mine sites and the communities. The uranium is generally found at the contact between the Archaean basement rock and the overlying Athabasca Sandstone. The earlier mines have been on the edges of the Athabasca Sandstone basin, where the contact is close to the surface. Later discoveries have been farther into the Basin, as evolving geophysical techniques allowed the discovery of deeper deposits. The Basin itself is not particularly productive, being sandy with low rainfall and low nutrient levels in the soil. Hence, the Basin does not produce abundant food and there are no permanent settlements in the middle of the Basin. Despite this situation, great concern has been expressed about the impacts of mines on communities and the cumulative impacts of the mines. The EIS guidelines required detailed examination of these issues.

In the past, the feasibility study and financial analysis that a company would do to satisfy its board of directors was considered sufficient justification for the economic basis of a project. A company was unlikely to invest money in a project that was not going to be profitable, and directors' due diligence would not permit this to happen. However, for McArthur River and Cigar Lake an extensive economic analysis was required to publicly demonstrate that a market existed for the uranium, that the projects were going to profitably recover that uranium and that all interested parties would get their share of that profit. It was pointed out by more than one intervenor that the panel was asking these questions but had no one with business credentials in its membership to provide the necessary financial assessment. Fortunately, these projects had such clear economic benefits that it did not take a high level of business acumen to reach a proper conclusion. The problem that this type of analysis presents for the proponents is that much of their business is opened to public scrutiny, which can be very detrimental in a highly competitive market.

Socio-economic issues are getting much more attention. The examination of these issues has gone far beyond what has traditionally been required. Because of the remoteness of the mine sites and the lack of roads, all the northern mines operate fly-in camps. Workers are picked up from small communities all over the north and flown into the mine sites, where they work for one week before returning home for a week off. These communities have grown beyond the capabilities of the local environment to support them by a traditional hunter-gatherer lifestyle, but because of their remoteness, there is little opportunity for wage-earning. The mines are one of the few sources of employment and (quite rightly) the provincial government through its surface lease agreements with the mines encourages the preferential hiring of northern residents. However, in assessing the McArthur River and Cigar Lake projects, the panel asked that extensive information be gathered on the impact of hiring northerners for mine jobs. Naturally it was known and expected that fly-in camps were disruptive to family life and do not work well for everyone. However, when one considers that the traditional lifestyle required a trapper to be away from home for days, even weeks, at a time, there is little difference, except that the transportation is more reliable and the camp accommodation more comfortable than a trap line affords. Nevertheless, the impacts of this type of employment had to be examined, with questions even being raised as to whether or not it is a good idea to create economic divisions within the community by giving people the well-paid mining jobs.

Questions such as the advisability of building roads were debated. Without exception the northern communities want roads to improve communication with the south and reduce the cost of bringing in supplies. But others, frequently not from the north, complained that building roads would open the north more and result in increased hunting and fishing pressure on limited resources. They also questioned the impact that easier communication would have on northern lifestyles. This debate did point out the generation gap, with many elderly people preferring the old ways (although recognizing that these would no longer support the larger community), while the youth clearly wanted the modern lifestyle that they see on television.

The net effect of all this social policy examination has been a number of panel recommendations for monitoring socio-economic impacts, community health and community vitality. This has resulted in the formation of several committees to examine these issues and develop monitoring protocols for matters that the committees themselves do not fully understand.

For all its value to the uranium business, McArthur River is a very small mine. At full production, it will produce only 125 tons of ore per day, compared with 1,000 to 2,000 t/d at earlier Saskatchewan mines such as Rabbit Lake and Beaverlodge and up to 8,000 t/d at some of the Elliot Lake mines. Unless the material being mined has some particularly nasty properties, the environmental impact of a mine is primarily a function of the mine production, both ore and waste rock. Ore transport impacts are also in proportion to production. An underground mine produces proportionately much less waste rock than does an open pit mine. In the case of McArthur River, much of the waste rock will be used as back-fill underground, further reducing the amount of waste rock to be left on surface at the end of the operation.

In situations where a mineral zone spawns several mines on adjacent properties, cumulative impacts are a serious consideration, e.g., the Sudbury nickel-mining area in Ontario. The impacts of several operations discharging effluent into a single stream can be significant and should be considered in the environmental assessment. However, in the northern Saskatchewan context, where mines range from 40 to 300 km apart and are generally discharging effluents into different water bodies, although possibly part of the same drainage basin, the concept of cumulative impacts is overworked. Yet, this has become another buzz word in modern environmental assessment; companies are asked to assess the cumulative impacts of operations that are hundreds of kilometers apart with no reasonable expectation of having anything other than a very localized impact. Cumulative air emissions had to be examined, despite the fact that no changes can be measured in airborne radionuclides at more than a couple of kilometers from any operating site. The cumulative impacts to air and water then had to be translated into dose and risk estimates for the distant northern communities.

The additional employment will be small. Because Key Lake is running out of ore, McArthur River ore will be processed there, meaning no new mill is required. The cessation of mining at Key Lake reduces the work force there. McArthur River will supply new jobs to replace those lost, but the net additional employment will only be about 125 jobs.

Certainly McArthur River will have an economic impact which is far out of proportion to its physical size and environmental impact. It will generate large amounts of revenue for the federal and provincial governments in the form of taxes, royalties, and lease and license fees. But these are positive impacts, which were more than adequately dealt with in the economic analysis.

Not only was the process long, but the requirements changed over the period with the net result that the hurdles continually got higher. Some of this change was as a result of the panel process itself (through recommendations in the earlier reports of the panel) and some was from normal regulatory/political evolution. We started the McArthur River process believing that we were providing more information than was required by any regulation: "going the extra mile". This was a conscious decision to produce the best EIS possible in order to minimize negative regulatory impact. Because of the changes in regulatory and panel perception, in the end we had done just enough work to meet regulatory and panel expectations.

From the perspective of nearly 25 years of participation in environmental assessments and public hearings, it becomes apparent that the "public" involved is a very small group indeed. The same individuals appeared as intervenors in the 1996-97 hearings as appeared in the 1977 Cluff Lake Board of Inquiry and all the hearings in between. This represents a small but vocal group of dedicated environmentalists who are philosophically opposed to industrial development generally and to the nuclear industry in particular. One of their strategies would appear to be to make the assessment process so onerous as to discourage proponents from proceeding. One must question the wisdom of catering the entire environmental assessment process to this small group.

Interested members of the public do attend sessions of the hearings but generally not for more than one evening or afternoon. Certainly there are people in the north of the province, closer to the mine sites, with genuine concerns and questions that should be answered. However, it is questionable whether a formal process conducted at the level of detail of these hearings is really necessary. Most of the questions could be answered in meetings without the formality and cost of the hearings.

The role of the regulatory agencies seems to have been forgotten in the zeal to promote public participation. Government agencies such as the AECB and the Saskatchewan Department of Environment and Resource Management (SERM) exist to protect the public interest. If the public had no interest in the matters being regulated by these agencies, there would be no need for these agencies to exist (nor would there be any need for hearings). If the agencies are performing their assigned tasks, then there is no need for others to act on behalf of the public.

In cases where there is a government agency which regulates the matter under review, we question the justification for intervenor funding. The argument put forward in support of intervenor funding is that the public, which is not expert in technical matters, needs the funds to hire consultants, etc., to assist it in examining the issues under review by the panel. Yet the government agencies exist for the sole purpose of protecting the public interest. By handing money to the public to independently analyze the issues, the assessment agency is suggesting that the government agencies are doing their job very badly. That being the case, the first issue to be addressed by any panel should be an assessment of the relevant government agencies. If these agencies are doing their jobs effectively, then there should be no intervenor funding. Taxpayers and proponents should not have to pay for both intervenor funding and an agency looking after the public interest.

The proponent faces a constant struggle over the level of detail required in describing the project and its impacts. Recent experience with the licensing of the McArthur River and McClean Lake projects has shown that the regulatory agencies are demanding more detailed analysis than they have ever demanded before. It is apparent that the agencies regard much of the information presented at hearings as superficial. The panel members are attempting to make an honest assessment of the project but they cannot be expected to bring the level of expertise of someone whose full-time occupation is studying the details of these projects. On the other hand the proponent is criticized for not making his documentation understandable to the public present in the hearings.

Environmental panels should not be turned into instruments of research. Many of the questions which proponents are being asked to address go far beyond what is reasonable and necessary to assess the projects. We estimate that the responses to this type of question from the current federal-provincial panel will cost the proponents approximately US$1,300,000. Public health studies in northern native communities may be worthwhile, but they should not be carried out under the guise of vital information required to assess a small mining project located over a hundred kilometers away from any community, and they should not be done at the expense of the proponent.

There is a fundamental difference between the federal and provincial processes. The provincial hearings are quasi-judicial, with sworn testimony and cross-examination. The federal process is informal, with no sworn testimony and very limited opportunity to question a witness. Such a process is designed to elicit opinion rather than scientific truth about a project. The proponent must submit an environmental impact statement, which is subjected to intense scrutiny by the panel and any experts it cares to employ. On the other hand, intervenors can make any sort of irrational statement about the supposed impacts of the project without the need to present proof. The more extreme cases are so transparent that even without cross-examination it is clear that the statements are wrong; however, a clever intervenor can sow the seeds of doubt in the panel's collective mind without going to extremes.

The provincial process certainly discourages indefensible statements being made about the project. Over all it is a better process for eliciting scientific truth and controlling the more extreme statements that opponents of a project may be prone to make. The value of the federal process is that it is less intimidating for the participants. However, that lack of formality and the inability to elicit the truth make it less valuable as an assessment process. If the objectives are to familiarize the public with the project, listen to their concerns and answer their questions, this could be better and more economically accomplished in community meetings.
As an educational process for the public, these hearings are, with few exceptions, an abject failure. Most opposition groups and opposed individuals appear only to present their briefs and to support each others presentations. Aside from panel and proponent staff, only a few individuals who could be termed public actually remain present to hear the majority of the presentations by the proponent. Those who wish to be recognized in the hearings, to present

written or oral briefs, should be required to attend some minimum amount of time, in particular listening to the presentations by the proponent and by any experts on those issues that the intervenor plans to address.

The increasing detail required in the assessment process is reducing flexibility for the proponent in subsequent dealings with the regulatory agencies. There is a growing tendency for panel recommendations to be treated as inviolate, rather than advisory. In Saskatchewan the ministerial approval is granted to carry out the project as described in the EIS with such modifications as may have been recommended by the panel. Any change in detail, even if it is an obvious improvement, must be formally reviewed and approved. This is a workable mechanism, but with the AECB, there is the added complication that a change from what was assessed must be screened for potential referral back to the assessment agency.

The AECB licensing process could also be made more efficient. The Canadian Environmental Assessment Act and regulations require that any project subject to a licensing decision by the AECB shall be screened for potential referral for environmental assessment. In the case of a project which has already undergone a public hearing, such a referral would be redundant. In fact the Canadian Environmental Assessment Agency is drafting protocols to ensure that a project only undergoes a single environmental assessment. For a project that has not undergone a formal environmental assessment, the AECB licensing process may be the only opportunity for public comment on the project. In this case the AECB policy of reviewing the license application at two meetings and soliciting public opinion in between is useful. However, in the case of a project such as McArthur River, which has undergone a six-year assessment process during which public opinion has been solicited nine times, including three public hearings, one must question the need for further delaying licensing with the AECB's formal process. Surely, anyone who had comments would have made them earlier in the proceedings.

7. CONCLUSIONS AND RECOMMENDATIONS

The major impacts of the environmental assessment process on Canadian uranium projects are delay of the project and added costs, both through the additional effort required in the assessment and through the delay of the project. The additional costs to the McArthur River project would probably be in the range of US$1,300,000 for work above and beyond what would have been done to adequately examine impacts. A far more serious cost is the one- to two-year delay in the start of production. The cost of this delay has been estimated between US$45,000,000 and US$110,000,000.

Intensive environmental assessment is a phenomenon of the late twentieth century. Some factions of our society are demanding ever more stringent examinations of new developments. If major impacts are not identified, then the assessment effort is blamed and additional examinations are demanded. Canada is a wealthy country, blessed with mineral resources rich enough to support this level of effort, but how long can we afford to continue along this path? Under the present assessment approach, small ore bodies, which would have been economical to develop 20 years ago, are no longer viable, because they cannot support the level of effort required to go through environmental assessment and licensing.

We must temper our environmental ardour and make assessment effort commensurate with the size of the project and its ability to do damage. We must more severely limit the matters which can be opened in an environmental assessment. Some consideration of socio-economic issues is justified, but a project which is going to create 125 new jobs in an area with 35,000 people, most of whom are unemployed, is not capable of an enormous impact and does not justify the depth of study which has been employed.

The principle of one assessment for one project must be upheld. The need for informing the public must be balanced against the efficient development of the project. For a project which has undergone extensive public review, there should be no need for further delays in the licensing to solicit additional public opinion.

Although these comments refer specifically to the Canadian regulatory regime, in general they would apply elsewhere. The case for public hearings is best made for completely new technology, for which there are no regulations and no industrial or regulatory experience. The uranium industry is a mature industry, regulated by agencies that have long experience and detailed knowledge of the industry. Recent developments have been in areas where there have already been uranium projects, which have been assessed in detail and are closely monitored. Under such circumstances it is difficult to justify a full-blown environmental assessment, as conducted for McArthur River and Cigar Lake. The licensing of such projects should be allowed to proceed through the normal regulatory process, without the need for extended studies and public hearings.

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RECENT INITIATIVES TO IMPROVE TAILINGS AND WATER MANAGEMENT IN THE EXPANDING AUSTRALIAN URANIUM MILLING INDUSTRY

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Abstract

This paper discusses the environmental and safety related changes that have recently occurred, or are about to be implemented in the Australian uranium milling industry. There are several drivers for these changes. The most important are the significant expansions to the Ranger and Olympic Dam uranium mills, the mining of a new orebody at Ranger and Government permission for the development of the Jabiluka deposit. The major changes in the operation of mines relate to the conservation and recycle of water, an important environmental issue in the arid country surrounding the Olympic Dam deposit, and tailings disposal strategies recently adopted or under consideration. These strategies include methods such as central thickened discharge, and cemented paste-fill for both underground and above ground disposal. The new ICRP 60 recommendations concerning radiation exposure have not been of major concern to the Australian industry, as dose rates have been historically less than the new limits. Current and expected dose rates are discussed in the context of these recommendations.

1. INTRODUCTION

Australia has a long history of uranium mining. The first major production was at Rum Jungle in the Northern Territory between 1954 and 1971. This was followed by Mary Kathleen, which operated over two periods between 1958 and 1982. Australia's second generation of mines commenced production in the 1980ís, with the development of the Ranger and Nabarlek deposits in the Alligator Rivers Region of the Northern Territory and Olympic Dam in South Australia. The Nabarlek deposit was exhausted in 1988 and rehabilitated in 1995, leaving only two operating mines.

These mines were developed and operate under strict regulatory control, which requires the implementation of best practicable technology to minimise environmental impact. Integration of rehabilitation/decommissioning requirements into operating plans is an essential feature of the long-term management of these projects. The two operating uranium mines are in diverse environments. The Ranger mine is located in a tropical zone, with wet and dry seasons, and management of run-off water is a key issue. The other site, Olympic Dam, is semi-arid with poor ground water quality, and water utilisation/recycle is a major consideration. Both sites operate under the concept of a restricted release zone, where no liquor entering the zone is discharged outside the zone. The major potential source of release is therefore seepage from the tailings disposal area and methods of tailings deposition are of significant importance.

The strong increases in uranium spot prices in 1995/96 and the predicted shortfall in worldwide production capacity has prompted Australia's existing producers to undertake major expansions. These expansions have offered the opportunity to incorporate recent advances in technology that will lead to improved environmental performance, water conservation and better occupational standards.

This paper describes the recent initiatives of the Australian industry to improve tailings and water management, with particular emphasis on proposals to use dry or semi-dry methods for tailings disposal. Although the new ICRP 60 recommendations concerning radiation exposure have not been of major concern to the Australian industry, current and expected dose rates are discussed in the context of these regulations.

2. CURRENT STATUS OF URANIUM INDUSTRY

Australia has two operating uranium mines; the Ranger mine operated by Energy Resources of Australia (ERA) and the Olympic Dam copper-uranium-gold-silver project of Western Mining Corporation (WMC). Both operations produce uranium by a conventional acid leach/SX flowsheet.

The Ranger mill commenced production in 1980. The nominal capacity of the mill was 3,000 t U_3O_8 from an ore averaging around 0.3% U_3O_8. ERA has now expanded its mill capacity from 1.4 million tonnes ore/year to nominally 2 million tonnes at a capital cost of about $A50 million. The planned annual production rate is about 5,000 tonnes U_3O_8, commencing in 1998.

The Olympic Dam deposit is one of the world's largest polymetallic orebodies, with known mineral reserves of 11.4 Mt of copper, 0.34 Mt of U_3O_8, 400 t of gold and 2,790 t of silver. Operation commenced in 1988 at an ore production rate of 1.5 million t per year from the underground mine. Uranium and copper production rates were 900 and 45,000 t per year, respectively. Since start-up, several optimization/expansion projects have been undertaken which have increased capacity to the current 3 million tonnes of ore per year, producing 85,000 t copper.

Following the approval of an EIS, submitted in 1997, WMC are currently undertaking a major expansion at Olympic Dam (ODO) to increase copper production to 200,000 t per year. The completion date for the expansion is the first half of 1999. As part of the EIS, a second phase of expansion to a copper production of 350,000 t per year was also approved. WMC has made no formal decision on the implementation of the possible second phase, however for the purposes of modeling scenarios presented in the EIS, an operational date of 2010 was assumed. At the projected production rates, Olympic Dam still has a life in excess of 200 years.

ERA has recently gained approval, through an EIS, for the underground mining of the Jabiluka deposit, which is nearby to Ranger, and for its preferred option to truck the ore to the Ranger mill for processing (Ranger Mill Alternative). Environmental approval has now just been obtained for the alternative of processing ore on the Jabiluka site (Jabiluka Mill Alternative), through the Public Environment Review process (of a lesser scale than an EIS).

Environmental approval for this second milling option was pursued due to the nature of the permission obtained from the aboriginal traditional owners of both Ranger and Jabiluka leases. Although existing agreements from traditional owners to mine and treat ore on each lease are valid, recently traditional owners have stated their opposition to the Jabiluka development and have declined to allow transfer of ore from Jabiluka to Ranger. Negotiations over which option should go ahead will continue with the traditional owners until ERA must make a final decision, in the near future, between the milling options.

A total of 19.5 million tonnes of ore is expected to be mined from Jabiluka at an average grade of 0.46% U_3O_8 yielding approximately 90,400 t U_3O_8 [1]. The lifetime of the operation will depend on the option chosen. For the Ranger Mill Alternative, production would range from 100,000 t per year of ore in year one rising to 900,000 t by year 14 until the final year 29. The corresponding U_3O_8 production would rise from about 670 to 4,000 t per year.

For the Jabiluka Mill Alternative, the mining rate would reach 200,000 t per year in year 2, and stay at this level for the first 10 years. For Stage 2, the mining rate would be increased to 900,000 t per year until the final year 29. The corresponding uranium yearly production rates are 2,500 t U_3O_8 for Stage 1, and 4,000 t for stage 2.

Construction of surface facilities common to both milling options commenced in June 1998. These comprise a water management pond, groundwater supply, surface facilities including a stockpiling area for ore and waste and a portal. The decline (access tunnel) to the orebody commenced in September 1998.

3. RADIOLOGICAL PROTECTION ASPECTS

The implications of ICRP 60 and more recent publications are discussed below, together with a summary of current doses and those projected from changes in operations.

3.1. Introduction of ICRP 60

The introduction of ICRP 60 brings with it several changes to current practice in Australia, these being:

(a) revised annual average dose limit (down from 50 to 20 mSv);
(b) revised tissue weighting factors;
(c) re-emphasis on optimisation of protection (ALARA); and
(d) the concept of "potential dose".

Because the two operating mines in Australia have managed to operate well within the 20 mSv/a dose range for many years, the introduction of a revised dose limit will not substantially affect either mine. In fact, the major expansions have provided opportunities to further reduce annual doses by improvements in equipment design and increasing ventilation rates.

Revised tissue weighting factors mean that effective dose calculations should now take into account changed dose conversion factors (DCFs). DCFs are considered in greater detail below.

Perhaps the most significant influence of ICRP 60 will be in the area of optimisation of protection. Australia has struggled with a mechanism for turning the ALARA principle into regulation, without a great deal of success in the past. ICRP 60 will mean a greater challenge to both the law makers and the mining companies.

The concept of potential dose seems to have limited application at mines.

3.2. Post-ICRP publications

3.2.1. Dusts

Various publications that followed ICRP 60 have more profound implications for uranium mining. The introduction of both a new lung model and new biokinetic models will mean a complete revision of DCFs. Table I shows how the new models affect DCFs for various mixtures of nuclides.

TABLE I. DCFs (mSv Bq^{-1})

AMAD	ICRP 61	New lung model and biokinetics		
	1 μm	1 μm	5 μm	10 μm
Insoluble U ore	0.20	0.088	0.066	0.040
Insoluble Th ore	0.37	0.081	0.060	0.036
Uranium mill tailings	0.07	0.057	0.045	0.027

Note that the default AMAD used prior to ICRP 60 was 1 μm whereas 5 μm is now the recommended default.

3.2.2. Radon decay products

The ICRP has examined the implications of the new lung model in terms of its implications for a dose conversion factor for radon decay products and has reached the conclusion that the lung model predicts about double the number of lung cancers than are actually observed in epidemiological studies. It has therefore recommended that the factor derived from epidemiology be used, not that from the lung model. The result is that the conversion factors are:

TABLE II. DCF FOR RADON DECAY PRODUCTS

Situation	Recommended value	Units
At home	1.1	mSv/(mJ h m^{-3})
At work	1.4	mSv/(mJ h m^{-3})
At home	4	mSv/WLM
At work	5	mSv/WLM

The factor derived from the new lung model is approximately double the values shown in Table II.

There is some debate in Australia as to the appropriate method of taking into account other radon decay product parameters such as the un-attached fraction and the aerosol size. This has not been resolved to date, but could have implications for underground uranium mining.

3.3. Olympic Dam

3.3.1. Mining operations

At Olympic Dam, the mean annual radiation dose in the underground mine in 1995-1996 ranged from just less than 2 mSv for a fitter, to just above 6 mSv for a production charger. Typically, about 10% of the dose arises from alpha-emitting radionuclides in dust, with the remainder of the dose equally split between gamma radiation and radon decay products [2].

The current mining method at Olympic Dam, a variant of sub level open stoping, will not change with the expansion. For this reason, individual radiation exposures are not expected to change with the increase in production rates. This is supported by plant data which shows that the annual mean radiation dose for mine workers has remained virtually constant over the last six years, even though the mining rate has increased from 1.5 to 3 million t of ore per year. As part of the expansion, there will be several changes in ore handling, including the use of driverless trains and remotely controlled crushing and loading stations. These improvements are in keeping with the company's commitment to ALARA to minimize dose.

3.3.2. Metallurgical plant

The metallurgical plant at Olympic Dam is far more complex than a conventional uranium milling operation because of the production of copper, gold and silver. The smelting operation, in particular, contributes a radiation dose not normally associated with a typical uranium processing flowsheet because of emissions of dust and volatile radionuclides. In this respect, Olympic Dam is unique as it is the only site in the world where co-production/processing of uranium and another metal is undertaken.

Like the mine, the annual mean radiation dose in the metallurgical plant has decreased since start-up because of improvements in operational and management practices, even though the plant throughput has doubled. The annual mean radiation dose in 1996 was 1.3 mSv. A breakdown of dose as a function of plant area is show in Figure 1.

The data in Figure 1 show that the mean annual dose in the hydrometallurgy area (equivalent to a typical uranium mill) was only 1 mSv. Average *potential* doses are further compared in terms of work category in Figure 2, which presents data *calculated on the basis of persons spending the entire year performing the specified task*. This analysis shows, that apart from the smelting operations where the alpha dose is significantly increased, the potential doses in the traditional uranium processing areas would be as shown in Table III, with uranium precipitation/product packaging yielding the highest dose.

As mentioned earlier, ODO has some unique features not normally associated with a uranium milling operation. Two areas of particular importance are the copper smelting operations and precious metals refining. As polonium-210, and to a lesser extent lead-210, are volatile under high temperature

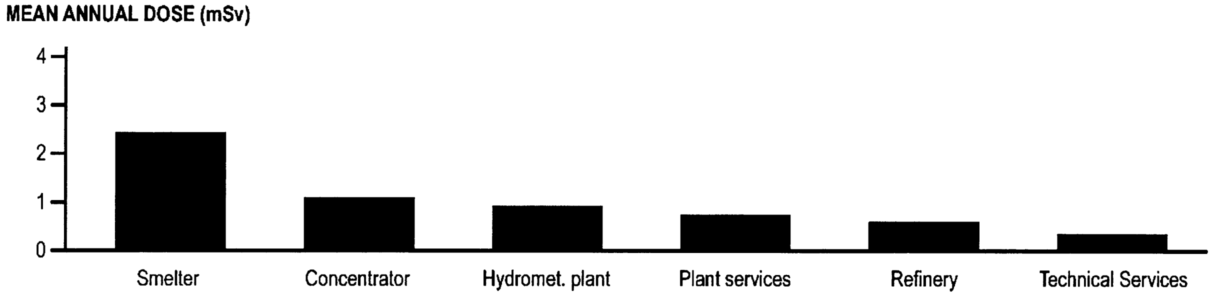

FIG. 1. Mean annual radiation doses at ODO by plant Area (1995-1996).

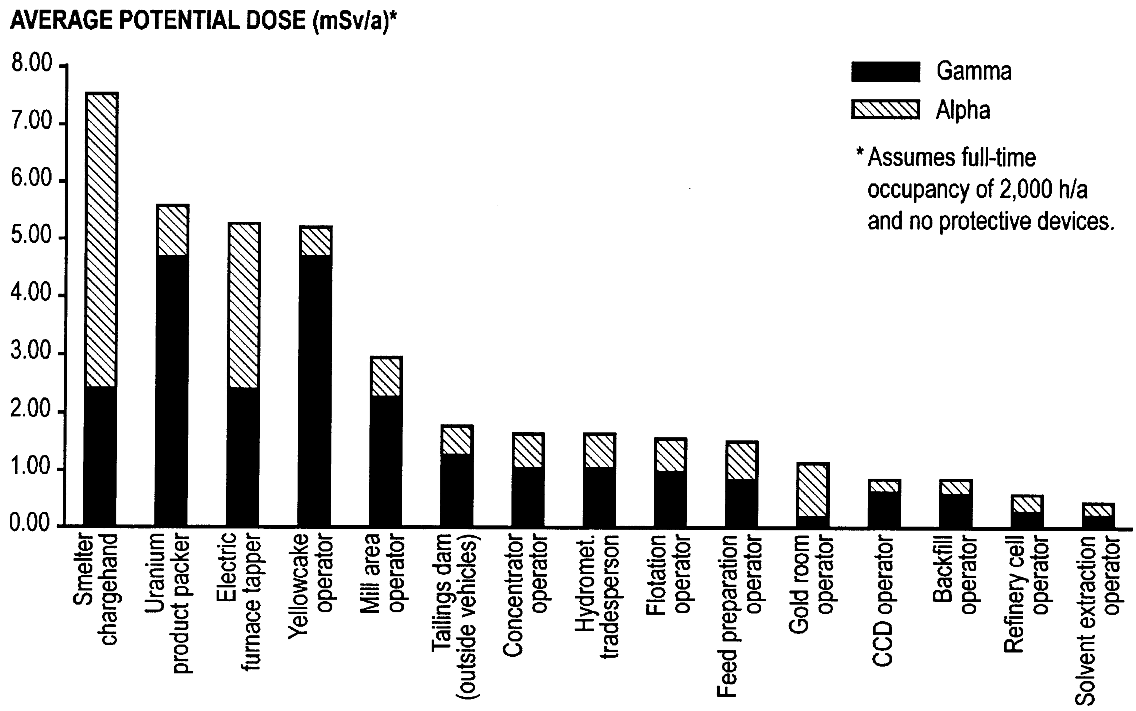

FIG. 2. Combined Alpha and Gamma potential doses in the ODO processing plant (1991-95).

TABLE III. AVERAGE POTENTIAL DOSE* (mSv/a)**

Plant Area	Potential Dose
Uranium product packer	5.5
Yellowcake operator	5.1
Mill area operator	2.9
Tailings dam	1.8
Hyromet tradesperson	1.5
CCD operator	0.7
Solvent extraction operator	0.4

* Source [2], ** For full-time occupancy of 2,000 h per year.

conditions, the inhalation of these radionuclides in airborne dusts is an exposure route that requires close attention. For this reason, control of fume and fugitive dust is an essential component of radiological protection. In this respect, protective measures for conventional hazards, such as half face respirators to prevent SO_2 inhalation also reduce occupational radiation exposure.

The importance of particulates has also meant that recent international research, such as lung models and biokinetic models, have influenced the assessment of doses. Particle sizing and solubility are both considered when calculating the occupational exposure of the workforce.

In the expanded plant, gamma and alpha exposure rates are predicted to be similar to the existing plant as ore grade and individual exposure times would not change. As part of the expansion, a new calciner and smelter are being constructed and the potential for exposure in these areas will be reduced further by careful design and planning**.**

3.3.3. Member of the public

Monitoring at ODO has shown that the radiation doses to members of the public from the operation are well below the public limit. The only two local communities are Olympic Dam Village and Roxby Downs, 12.5 and 5 km, respectively from the site. For this location, the atmospheric pathway is the only one of relevance.

In order to predict the possible impact of the expansion on dose rates, it has been assumed by WMC/ODO that dose is correlated with production rates to provide an upper bound estimate. These predictions are compared in Table IV. The predicted radiation doses are between 1 and 3% of the annual average dose limit for members of the public of 1 mSv, over and above background.

3.4. Ranger operation

The expansion of the Ranger mill introduced no changes to equipment of operational procedures that would impact on radiation doses. The annual average dose for the last two years for designated mill workers has varied from 3.8 to 5.5 mSv.

The deposition of tailings in the No. 1 pit and the subsequent removal of the tailings beaches in the tailings dam has reduced the potential γ-exposure from the dam.

TABLE IV. UPPER BOUND ESTIMATES OF DOSE TO DUE TO EXPANSION** (mSv/a)

Production Status	Olympic Dam Village	Roxby Downs
Current	0.022*	0.017*
After expansion	0.053	0.042

* Average of 1991–1996 data, ** Source [2].

3.5. Jabiluka development

3.5.1. Mining operations

The proposed underground mining method at Jabiluka is a variant on long hole open stoping. The drill and development galleries will be in barren, rather than ore zones. The radiation doses predicted for the mine are presented in Table V. The data presented are for the early years of operation when the ore grade will be at its highest level. As the maximum predicted dose is 14 mSv/a, a management system to control radiation doses will be an integral part of the operation of the underground mine [1].

TABLE V. PREDICTED RADIATION DOSE TO UNDERGROUND PERSONNEL*

Category	mSv/a
Development miners	14
Production miners	9
Backfill and service workers	8
Supervisors	13
Foremen and technical services	10

* Source [3].

A sensitivity analysis of the model used to predict the exposure has indicated that, because of the mining method, it will be necessary to closely monitor gamma radiation in the mine, and to examine all possibilities for dose reduction. It will be a priority at Jabiluka to refine predictions using actual measurements as an increase in the gamma dose by 50% would increase the maximum radiation dose to 25ñ30 mSv/a [1], which is greater than the ICRP 60 recommended limit.

3.5.2. Metallurgical plant

The estimated annual radiation exposures of personnel working at Jabiluka are shown in Table VI. The estimates are based on data for Ranger. The doses are only 2–3 times those measured at Olympic Dam, even though the uranium grade is almost an order of magnitude greater, because of the higher dust activity at Olympic Dam associated with the smelting operation.

TABLE VI. RADIATION DOSE ESTIMATES FOR JABILUKA PLANT PERSONNEL (mSv/a)*

	Dust	Gamma	Radon Daughters	Total
Plant operator	1.7	0.4–1.4	0.4	2.5–3.5
Maintenance	1.8	0.13–0.8	0.4	2.3–3.0
Workshops	0.8	0.01–0.3	0.4	1.2–1.5

* Source: Jabiluka Mill Alternative PER [3]

3.5.3. Member of the public

Radon from mine vents and emanating from surface stockpiles, together with uranium discharged from the calciner stack was modelled in a dispersion model to estimate the dose to a member of the public. The nearest settlement was taken as Mudginberri, 10 km from the plant. The predicted radiation dose is less than 1% of the annual average dose limit for members of the public [3].

4. TAILINGS MANAGEMENT

The deposition/storage of tailings has always been a major environmental issue facing the uranium, and other mining industries. For this reason, there has been a continual evolution of tailings management practice in the Australian uranium industry. At present, managed sub-aerial deposition strategy is used at both Ranger and Olympic Dam, although some recent tailings deposition at Ranger has been sub-aqueous.

Although there are many factors to consider, in-place density, impounded solution volume and long-term consolidation are the main factors affecting the overall performance of a tailings storage facility. These potential problem areas stem from the presence of excess water in tailings stored in impoundments and the amount and fate of seepage water and its contained solutes. This is recognized by the Australian industry and there are several proposals under investigation to use dry or semi-dry disposal alternatives. Local conditions also play an important role, particularly in regard to liquor management. For this reason, the disposal alternatives are discussed on a site-by site basis.

4.1. Ranger uranium mine

The No. 1 orebody was mined out between 1980 and 1994. The final open cut is approximately 750 m x 750 m x 175 m deep. In 1996, Ranger commenced development of the No. 3 orebody, which is located about 1.2 km from the No. 1 pit. Production from the No. 3 orebody commenced in 1996 with full-scale operation in 1997. Considerable stockpiles from Pit No. 1 were available to feed the mill whilst Pit No. 3 was brought into full production. A blend of ore is currently fed to the mill.

Until August 1996 tailings from the processing of the No. 1 orebody were pumped to a 107 ha above-ground tailings dam, with a nominal capacity of 15 Mm^3. The tailings were originally deposited by the sub-aqueous technique, with a water cover of 2 m. With this method, consolidation of the tailings was poor and the settled density of tailings was less than 1.0 tm^{-3}, significantly less than estimated for sizing of the tailings dam. When subsequent research showed that maintaining the tailings in a moist state was sufficient to achieve the desired radon release rate, tailings were deposited subaerially (from 1987) and maintained in a saturated condition. Following this change, settled densities were increased but the average density in the tailings dam remains at a little over 1.0 t m^{-3}. Beached tailings in the tailings dam average greater than 1.2 t m^{-3} on an annual basis, although the density of recently deposited beaches is initially lower until draining is complete.

Following environmental approvals, the neutralised tailings slurry from the mill is now being deposited in the mined-out No. 1 pit, which has a capacity of 21 Mm^3. Tailings are deposited from several deposition points to enhance beach development and control the location of the decant pond. Sub-aerial deposition is carried out when possible, but following a series of wetter-than-average years the majority of deposition in Pit No. 1 has been sub-aqueous. Various measures have been undertaken to remove excess tailings water. The most significant of these has been dredging of the beaches in the tailings dam to re-establish the dam as a full, year-round evaporation surface. Irrigation of tailings water on the walls of Pit No. 1 will be implemented. This is similar to a measure used at the Nabarlek uranium mine in the mid 1990s [4].

To minimise the permeability of the tailings, and thus minimise the volume of water contained within the tailings that can drain out, ERA is required to achieve a minimum density of 1.2 t m^{-3}, to be demonstrated at each 20 m thickness of tailings. ERA has committed to a minimum average density for the filled pit of 1.3 t m^{-3}. This is being achieved by the use of an underdrainage system connected to an adit and borehole to accelerate compaction [1]. This approach has proved successful with densities currently running at

1.26ñ1.32 t m^{-3}. Higher density will also simplify rehabilitation, as the tailings will eventually be capped with rock and revegetated either as a low hill or as a centrally-draining depression. Provision has been made for possible additional drainage layers or wicks to be used to further increase this figure as the thickness of tailings increases, if required. In July 1998 tailings were equivalent to 68 m depth in the deepest part of the pit.

The in-pit disposal system adopted at Ranger has parallels to those adopted for tailings management at the Rabbit Lake mine [5] and elsewhere in Canada [6]. In-pit deposition of tailings, then capping and revegetation, at the much smaller Nabarlek uranium mine not far from Ranger, was successful without the use of underdrainage [4].

When approvals were given for the initial development of the Ranger No. 1 orebody, it was stipulated that all tailings at Ranger must be deposited in or transferred to the mine pits unless another proposal was made and accepted by the government. The alternative of in-situ rehabilitation of tailings within the existing dam has been under consideration for some time. The criteria to be satisfied was that the any alternative must result in the environment being no less well protected than by depositing or transferring the tailings to the mine pits. The issues involved in the assessment of alternatives are set out by Waggitt [7] and Woods *et al*. [8].

After considering all factors, and in particular the requirements of Best Practicable Technology as set out in the agreements and government conditions imposed on Ranger [8, 9], the recommended best practice for disposal of tailings was judged to be below grade whenever practicable [9]. This decision was endorsed by the ERA board and announced in December 1997. The major reason for preferring this over a tailings dam is there is no risk of failure of the walls of the containment structure over the extended periods required for uranium tailings containment, and that the mildly radioactive material is returned to the geological context from which it came. Some tailings (less than 300,000 m^3 to August 1998) have already been transferred from the tailings dam to Pit No.1, largely for process water management reasons. A decision is yet to be made as to whether to transfer the tailings during the remaining mining operations or as part of final rehabilitation when the site is decommissioned.

Transfer of tailings is by conventional dredging with a balancing return of tailings water from Pit No. 1 to the tailings dam. Some remediation of a small permeable section of the upper walls of Pit #1 may also be required [1, 10]. Depending on the location of the mill for Jabiluka ore, the active Ranger pit No.3 may or may not also be required as a tailings repository. There is enough space in the two Ranger pits to store all tailings from both Ranger and Jabiluka projects, as ore reserves currently stand [1, 9, 10]. Depending on the amount of tailings held and resolution of water quality issues, Ranger No. 3 pit may be converted to a lake during rehabilitation [11]. Current indications are that some remediation of more permeable sections of the upper wall of Ranger No. 3 pit may be required if it is used as a tailings repository [1, 10].

4.2. Jabiluka

4.2.1. Paste-fill method

For management of tailings at Jabiluka, should milling proceed there, ERA is proposing the use of a new generation best practice method that is currently being taken up by the mining industry [3]. This method, cemented paste-fill, has evolved from research into the use of tailings as backfill in underground mines and results in greatly improved deposition characteristics.

In paste deposition, the tailings stream is physically dewatered to produce a high density paste (typically 65–70 wt%), similar to wet concrete, which is then pumped to the tailings containment area. The resulting deposited material has a minimal free water content and a very low hydraulic conductivity. The low water content means that it becomes feasible to add a binding agent such as Portland cement to increase the strength of the tailings and further reduce the conductivity. Paste fill systems also have the advantage that the slimes fraction does not separate from the tailings following deposition. In addition, because most solution is recovered in the paste production process, the costs of recycling solutions from ponds and underdrainage collection networks are virtually eliminated [12].

4.2.2. Underground disposal

Paste fill has been used for underground disposal of tailings in mines in South Africa [13, 14], Germany, Canada and USA.

The current proposal for Jabiluka is to dispose about 75% of the tailings produced as underground backfill. Due to the swell associated with the ore processing operation, only this proportion of the tailings can be accommodated underground in planned voids. Cemented paste-fill is planned for both above ground and underground applications. For underground disposal, approximately 80% of the tailings would receive a 4% cement addition before being pumped to primary stopes. The remainder of the tailings sent underground would have a 1% or more cement addition and would be preferentially pumped to secondary stopes as the underground void became suitable for such disposal [3]. Supernatant water expressed from the tailings would be pumped to a no-release process water management circuit.
Underground paste disposal contrasts with an earlier, more conventional, strategy proposed for a Jabiluka mill alternative [1], where the tailings were to be separated into coarse and slimes (< 20 μm) fractions by hydrocycloning, with the coarse fraction to be mixed with cement for use as underground backfill. The slimes were to be pumped to surface tailings dams and deposited sub-aerially. A particular advantage of paste fill for Jabiluka is that it would remove the need to consolidate and dewater the slimes, which would also require more effort and expense to cap securely. The potential for seepage and interaction of tailings with ground waters would also be reduced because of the inherent characteristics of the paste.

Government approval (August 1998) of the Jabiluka Mill Alternative PER [3] provides for a base case of 100% return of tailings to the deep mine workings, until further studies on the hydrogeology and other aspects of tailings disposal in specific pits are completed to the satisfaction of the authorities. These studies are currently under way and may modify the proposal from the PER described below. Should 100% of tailings be returned to the deep underground, specific voids will need to be created, with waste rock stored on the surface. Detailed mining plans allowing for this potential variation are being prepared.

4.2.3. In-pit disposal

For disposal of tailings that cannot be easily accommodated in the deep mine workings, ERA have proposed that the residual tailings are mixed with a 1% cement addition and pumped to purpose-built open pits. This would involve excavation of pits, specifically to contain the tailings, in benign, non-mineralised sandstone. Another advantage of the paste-fill technique is the equivalent neutralising capacity of the cement, which could account for any incipient generation of acid. Only a small proportion of Jabiluka tailings are predicted to be acid producing, and some of the acid producing potential will be destroyed during the milling process which is carried out under strongly oxidising conditions.

If pits are used for disposal, it is proposed that they would be an integral part of the water management system. In this case, the pits would be used for storing surplus wet season run-off from the process plant and ore stockpile areas. When the pit contains a sufficient depth of water, the paste would be deposited sub-aqueously from a floating pontoon, with the discharge within 1 m of the surface of the tailings to ensure that the physical integrity of the paste was maintained. At other times, the paste would be deposited across the surface of the exposed tailings using a boom spreader.

4.2.4. Paste-fill production

Current plans for paste fill production are as follows. These may be modified during actual construction, should it proceed, should more appropriate methods be available. The underflow slurry from the CCD washing circuit would be treated with lime in a dedicated circuit to increase the pH to about 5. The neutralised slurry is stored in a large agitated tank to provide surge capacity for the paste fill plant. The neutralised tailings slurry would be filtered on a single belt filter and the resultant filter cake would be repulped with a cement additive prior to being pumped to the disposal areas.

4.3. Olympic Dam

The tailings at Olympic Dam are discharged by sub-aerial deposition into an above ground tailings storage facility (TSF). This method is ideally suited to the Olympic Dam climate where evaporation rates are 14–18 times rainfall.
Supernatant liquor decanted from the tailings is pumped to a series of evaporation ponds. Before discharge, a portion of the acidic tailings slurry is directed to a desliming plant, where the coarse fraction is separated by hydrocycloning, neutralized and used in cemented aggregate fill (CAF) for underground mine fill. At present approximately 4% of the tailings is disposed of underground. The slimes from hydrocycloning are thickened and combined with the bulk of the tailings slurry, which is discharged to the TSF at a solids concentration of 40–50 wt%.

A portion of the liquor from the evaporation pond is combined with tailings prior to deposition in the storage cells. Some of the tailings liquor and contained salts remain within the pores of the tailings solids. This process enables the concentration of dissolved salts in the ponds to be controlled, as excessive levels would result in reduced evaporation rates and precipitation of salts in the evaporation ponds.

4.3.1. Above ground disposal of tailings

At present about 2.7 Mt are discharged annually to the TSF. This will increase to about 7.0 Mt when the expansion is completed. The existing tailings system consists of:

> A paddock method tailings storage facility, comprising three storage cells of about 190 ha total area, with each cell having its own decant facilities for supernatant tailings liquor; and

Two clay and HDPE-lined evaporation ponds, each divided into four cells, with a combined evaporative area of 68 ha. The ponds are used to dispose of tailings liquor and excess acidic process liquor, such as a raffinate bleed and liquor recovered from thickening of the slimes.

The tailings are deposited from spigots along a distribution pipe running along the perimeter walls. A thin layer of tailings about 100 mm thick is deposited during each deposition cycle and allowed to dry for a period of about three to four weeks. The layer reduces to about 60 mm during the drying process. Deposition takes place over a length of approximately 200 m. The tailings beach has an average slope of approximately 2% over the first 200 m and about 1% thereafter. The current height of the perimeter wall is 12 m and the maximum planned height is 30 m.

The densities of the deposited dry tailings are of the order of 1.6–2.05 t m^{-3}, with an average of approximately 1.7–1.8 t m^{-3} (particle density is 3.2–3.6 t m^{-3}). The moisture content of the tailings is approximately 20–25 wt%, corresponding to a pore saturation of 75–100%.

Two tailings storage systems were considered for the expansion of the facility. These are:

(a) continuation of the existing paddock tailings storage method, with the construction of additional cells similar to the existing; and
(b) adoption of a new method, central thickened discharge (CTD) involving further thickening of the tailings slurry and discharge through central risers to form a final tailings profile resembling a series of intersecting flat cones.

4.3.2. Expansion of sub-aerial discharge system

Expansion of the existing system would involve staged construction of another two tailings storage cells with a combined area of 340 ha, increasing the overall area to 530 ha. The maximum height of the embankments would be 30 m. The floor of the storage cells would be covered by a 0.3 m clayey soil liner. Additional evaporation ponds of about 40 ha would also be provided.

A key design criteria of the expanded facility would be minimization of seepage, including minimizing the amount of supernatant liquor on the tailings and maximizing evaporation from the tailings surface. To achieve these goals it is necessary to restrict the rate of rise to 1–2 m per year (current practice), which should ensure removal of all free liquor from the tailings.

Supernatant liquor would continue to be removed from the cells using central decants and then transferred to the evaporation ponds. Seepage from the supernatant pond would be minimized by providing an underdrainage system below the expected maximum footprint of the supernatant pond.

The focus on seepage minimization follows previous detection of seepage from under the TSF and other ponds. The seepage was in part attributed to the operating strategy adopted in the initial years of operation of the TSF. Unlike some sub-aerial systems, water was not withdrawn from a central sump, but was allowed to pond in the middle and evaporate in-situ. As the groundwater contained highly saline water, that was unfit for human or animal consumption, there were no harmful effects on the environment [15].

The tailings system was modified to the present arrangement in 1994 and 1995 to allow for:

(a) removal of tailings liquor from the top of the cells; and
(b) construction of the lined evaporation ponds.

4.3.3. Central thickened discharge

The CTD method was evaluated in pilot trials and feasibility studies, and has potential to offer economic and operational advantages at Olympic Dam over the current system. This method, which was originally suggested by Robinski [16], is being used in Australia at four sites; Mount Keith, Gove, Elura and Peak.

The optimum CTD method is tailor made for a particular site to suit the tailings rheology, disposal rate, project life, topography, tailings liquor composition, soil profile and hydrogeology.

At Elura and Peak a single deposition location is used. Elura uses a storage area with three radial partitions. Mount Keith uses a number of central risers and Gove uses a longitudinal stack with a series of risers.

The optimum CTD arrangement developed for Olympic Dam involves the discharge of thickened tailings initially along a series or ridges arranged over existing sand dunes. A number of ridges are used to limit the rate of rise of tailings during the initial beach development. Deposition would occur from a number of spigots arranged along the length of each ridge. Deposition would eventually occur only from the central ridge to form a single longitudinal. The height of the tailings ridge would be 30–35 m above the natural ground level. A pipeline around the perimeter of the outer embankment would convey the collected supernatant liquor back to the process plant or to the evaporation ponds.

Advantages of CTD at Olympic Dam are considered to be:

(a) greater operational flexibility in terms of rate of production and deposition of tailings;
(b) the system holds a greater volume of tailings for any given embankment height;
(c) operating costs are less;
(d) there are increased opportunities for water recycle as more water is recovered before deposition and stormwater runoff would be greater due to increased surface area. Evaporation potential from the deposited tailings will be greater because of the larger surface area.

Disadvantages are as follows:

(a) a greater land area is required to store a given volume of tailings;
(b) higher initial capital costs;
(c) drains and structures are required over the area not covered by tailings to control and collect supernatant tailings liquor.

Extensive field trials have been carried out which indicate that the maximum solids concentration that can be achieved in a thickener prior to discharge would be 55–60 wt%, resulting in a beach slope of about 2.5% for vertical discharge and 2% for side discharge. For

20 years of production after the expansion, the storage area would about 660 ha. Features of the overall design include:

(a) tailings delivery pipes would be on causeways on the surface of the tailings;
(b) supernatant liquor and stormwater are collected in lined reclaim ponds, which would overflow into stormwater ponds following significant rainfall; and
(c) floor preparation of the area will not need to be as extensive as for the paddock system currently in use as less supernatant liquor would result because of the higher initial solids concentration in the tailings slurry.

Field trials were undertaken to provide data to design a filling strategy that ensures that the tailings mound would be stable under all operating conditions, including extreme meteorological events. The radon release rate from the CTD system would be greater than for the paddock system because of the greater surface area, but this has no significant implications for radiation doses.

4.3.4. Underground disposal of tailings

After removal of ore from primary stopes the voids are backfilled with cemented aggregate fill (CAF). CAF consists of crushed waste rock, or rock obtained from a surface dolomite quarry and neutralized deslimed mill tailings or dune sand with the addition of Portland cement and pulverized fly ash. The addition of cement is about 2% wt of the total mixture and flyash is about 4%. The proportion of deslimed tailings (sand) in CAF is about 25 to 30% wt which will represent about 17 to 20% of the total tailings.

Historically the amount of tailings used in CAF has been limited to about 5% of the total tailings due to technical difficulties associated with pumping deslimed tailings and the availability of surplus dune sand which can be used in lieu of the deslimed tailings sand.

The amount of deslimed mill tailings which can be returned to the mine is limited by the requirement to provide an economical CAF with adequate strength.

Paste technology has been considered but is not economically viable at present due to the increased requirement for cement and flyash to achieve the required strength.

5. WATER MANAGEMENT – OLYMPIC DAM CASE STUDY

5.1. Background

The nominal average production rates at ODO for the current and expanded plant are shown in Table VII. The average uranium and copper grades for the period 1998 to 2010 are predicted to be 0.072 and 2.4%, respectively, which are slightly less than in the earlier years of operation.

TABLE VII. NOMINAL YEARLY PRODUCTION AT OLYMPIC DAM

	Ore (Mt)	U_3O_8 (t)	Cu (t)	Au (kg)	Ag (kg)
Existing mill	3.0	1500	85,000	850	13,000
Expanded mill	8.7 – 9.2	4,630	200,000	2050	23,000

5.2. Process flowsheet

Uranium is recovered by a conventional acid leach, solvent extraction, ADU precipitation and calcination process. However, the overall flowsheet is very complex because of the co-production of copper, silver and gold. However, in terms of water management and tailings disposal, the uranium processes tend to dominate. A simplified flowsheet is shown in Figure 3.

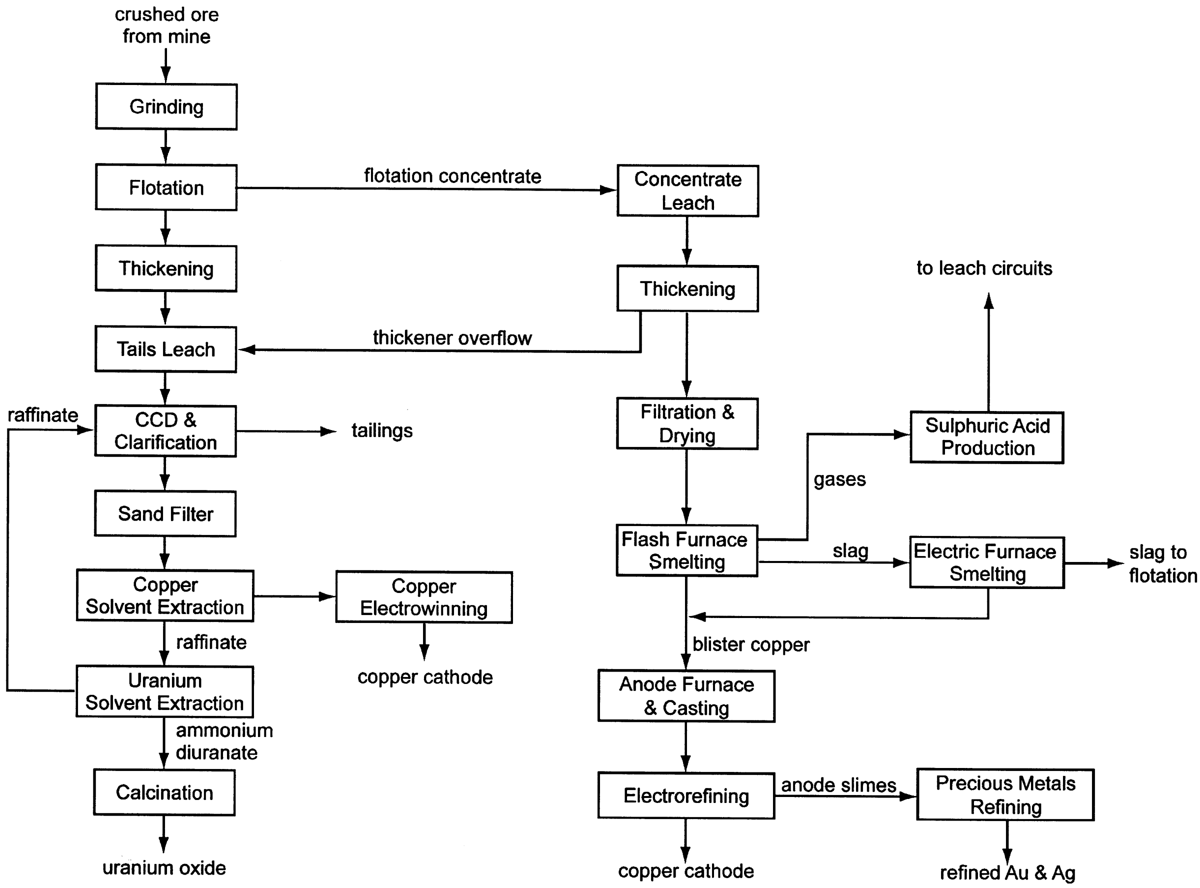

FIG 3. Simplified Flowsheet of Olympic Dam Operation.

The major ore minerals consist of copper sulphides and the uranium minerals, uraninite, coffinite and brannerite. The ore is first floated to produce a copper sulphide concentrate and a flotation tailings, which contain the bulk of the uranium in about 90% of the mass of the ore. The copper concentrate is leached in a dedicated circuit to dissolve uranium that reports to the concentrate. After solids/liquor separation, the leach liquor is added to the main uranium leaching circuit. The leached concentrate is smelted to produce blister copper, which is subsequently converted to anodes that are electrorefined to produce high purity cathode copper. A high proportion of the gold and silver in the ore report to the anode slimes generated in the electrorefining process. The slimes are treated to produce high purity gold and silver.

The flotation tailings are thickened from 28 to 62-63 wt% and then fed to the tails leach circuit. The neutral liquor from the thickener overflow is recycled to the milling circuit. In the tails leach, uranium, and a substantial proportion of the remaining copper not recovered by flotation, are leached at a temperature of 55°C and at a free acidity of about 10 g L^{-1}. The

leached solids are washed in a CCD circuit using recycled raffinate. The pregnant liquor is first treated by solvent extraction to remove copper, which is recovered from the strip liquor by electrowinning. Uranium is then recovered from the copper raffinate in conventional solvent extraction/ammonia precipitation circuits.
The tailings solids from the CCD circuit are pumped to a storage facility.

5.3. Expansion

In the expansion, the mining method and metallurgical processes remain essentially unchanged, and are thus well understood. The major areas re-assessed to take advantage of recent advances in technology and changes in environmental requirements include:

(a) the sustainable supply of water;
(b) the containment of tailings; and
(c) the management of radiation exposures.

The latter two issues are covered in Sections 3.1 and 4.3. The importance of water supply is discussed in detail here.

5.4. Water supply

Groundwater at Olympic Dam is highly saline, with a total dissolved solid in the range 20–40 g L^{-1}. Owing to its salinity, the groundwater is not used as a plant water supply, but is extensively used underground for dust suppression and drilling.

Water for potable and process uses at Olympic Dam is obtained from the Great Artesian Basin (GAB). The GAB is a groundwater basin that underlies about 1.7 million km^2 of central Australia. The total water storage is estimated to be 8,700 million ML.

The current total raw water use from the GAB is 15 ML/d. Potable water is produced in a desalination plant and is used in the local town and plant for personnel facilities and in processing where desalinated water is required. Process water (TDS of 2,300 mg L^{-1}) is used in the metallurgical plant for processing operations. It comprises raw water and the reject water from desalination. Process water accounts for 70% of the supplied bore water.

The cost of water at Olympic Dam is quite high, as shown in Table VIII. This factor, and a desire to conserve water, has driven the implementation of water minimisation programmes.

There are essentially two process water circuits in the overall metallurgical process (see Figure 4). The first is the neutral circuit, which comprises the milling and flotation circuits.

TABLE VIII. WATER COSTS* ($/kL)

	Cost
ODO Process water	1.61
ODO Potable water	2.40
City water**	0.88

* Source [2], ** Water pricing in major capital city.

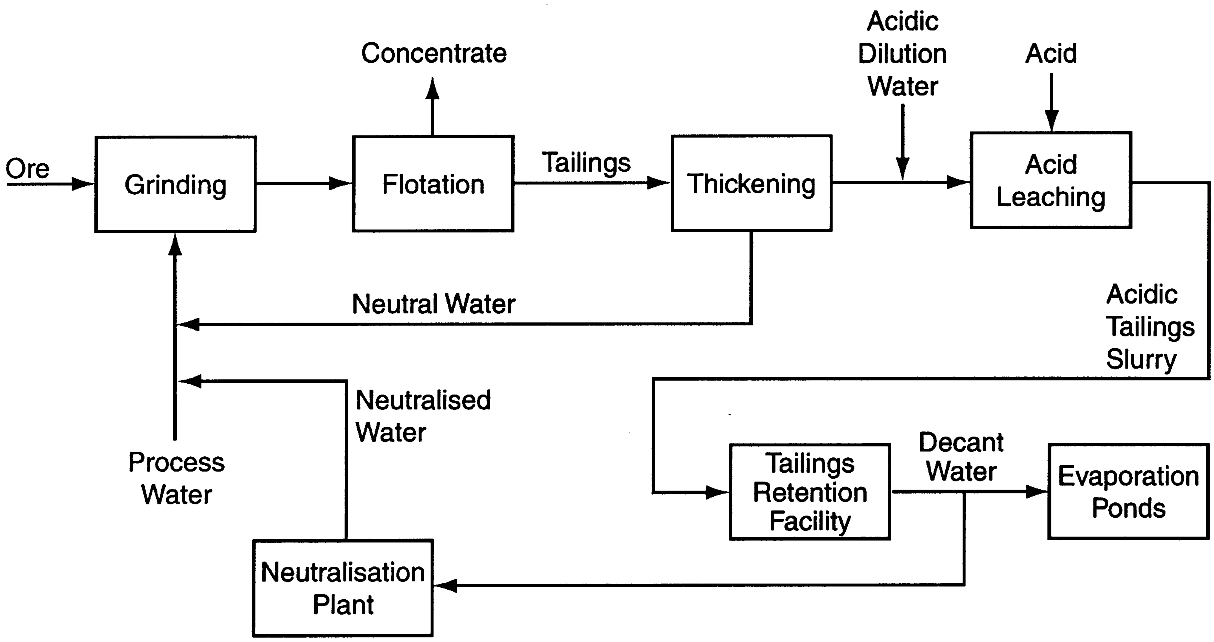

FIG 4. Process water circuits at Olympic Dam.

This circuit is a major consumer of water, with water "lost" from the circuit with the flotation tailings thickener slurry. The lost water enters the acidic liquor (leaching) circuit and exits the plant with the leached tailings.

Water usage in the plant will increase to about 30 ML/d when the expansion is completed. This equates to 1.24 kL t^{-1} of ore milled, compared to a pre-expansion usage of 1.57 kL t^{-1}, a reduction of 21%. This saving will be achieved, despite increased water usage in some scrubber operations, by the following measures:

(a) installation of high compression thickeners in the concentrator for increased recovery of neutral process water; and
(b) construction of a neutralisation circuit to allow treatment and recycle of acidic tailings water to the neutral, front end of the process.

The first measure involves the use of 2 × 38 m diameter, high compression thickeners, each handling 550 t h^{-1}, to dewater the flotation tailings feed to the main uranium leaching circuit. The thickeners will have a nominal mud height of 3 m and be equipped with an educt system for feed dilution to 15 wt% solids. Compared to conventional thickeners, the underflow density will be increased on average from 62.5 to 70-72 wt%, recovering an additional 4.5 ML/day for recycle to the milling circuits. As the increased density is too high for effective agitation in the subsequent leach circuit, acidic tailings liquor recovered from the tailings storage facility will be recycled to achieve the desired density in leaching.

Recycle of acidic tailings liquor to the process is an obvious approach to further reduce the net water consumption of the process. To make a significant impact in this regard, water must be recycled to the grinding circuit where the ore is first slurried, but to avoid corrosion of the grinding mills and provide the appropriate conditions for the flotation circuit, a near neutral pH is required.

As part of the expansion, a neutralisation circuit is being constructed, partly using redundant equipment. The circuit will treat of 5 ML d^{-1} of acidic water recovered from decanting/settling of leached tailings slurry. The circuit consists of six agitated tanks and four small high rate thickeners. Initially, lime will be used to raise the pH from about 1 to 7, but this will probably be replaced by calcined dolomite, mined from a local quarry. A feature of the process is the incorporation of the HDS approach of recycling thickener underflow to increase the settled density of the gypsum/metal hydroxide sludge produced.

For the Olympic Dam acidic liquor, which has a TDS of 45 g L^{-1}, the HDS process should allow the recovery of 94% of the liquor, compared to 87% from conventional neutralisation, where a more gelatinous sludge is produced. The volume of sludge produced by the HDS process is also about 50% less than from conventional neutralisation. The sludge will be disposed of in the tailings retention system. The decision to apply the HDS process to the treatment of liquor with a high total dissolved solids content was based on the results of continuous mini-scale trials using both lime and calcined dolomite conducted at ANSTO [17].

The scope for increasing the recycle of acidic water at Olympic Dam is limited by the potential build-up of salts and organic contaminants which could have a detrimental effect on process efficiency. Chloride ion introduced by the use of sodium chlorate as an oxidant in uranium leaching and as a constituent of the ore (from groundwater) is the major limiting factor as its concentration reduces the loading of uranium in solvent extraction.

6. CONCLUSIONS

Significant expansions in production have given Australia's two uranium producers the opportunity to adopt/assess advances in technology that will lead to improved environmental performance. The most significant changes that have taken place or are being considered involve tailings deposition. These include:

(a) the decision to transfer tailings from the Ranger tailings dam to the mined out pits for final containment and rehabilitation;
(b) the deposition of the current production Ranger tailings into a mined-out pit with an underdrainage system to ensure a high settled tailings density;
(c) the plan to use the cemented paste fill method for the placement of tailings in the proposed underground Jabiluka mine;
(d) the continued assessment of the more novel use of the paste method for disposal of tailings in purpose-built open pits; and
(e) consideration of the central thickened discharge method as an alternative to the existing sub-aerial discharge system for the expansion of the Olympic Dam tailings storage facility.

The other major area of environmental importance to receive attention is water conservation in arid regions. By using more efficient solid/liquid separation equipment and installing a treatment circuit to neutralise acidic water, the Olympic Dam operation will reduce the water consumption per tonne of ore milled by in excess of 20%.

The new ICRP 60 recommendations will not, in general, impact on the Australian uranium mining operations. Nonetheless, a careful management system will be required to control radiation doses at the underground mine proposed for the Jabiluka development.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of Messrs Tim Harrington of Kinhill Pty Ltd, Frank Harris of ANSTO and Tony Martin of ERA to the section on radiological protection.

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NUCLEAR REGULATION OF SOUTH AFRICAN MINES: AN INDUSTRY PERSPECTIVE

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Abstract

South African mines have become subject to a rigid and prescriptive system of nuclear regulation that has its roots in the past when South Africa embarked upon a period of nuclear development spanning the full nuclear fuel cycle, and in which the South African gold mining industry once played a major part in the supply of uranium as a low grade by-product. Radiation hazards in the mines are generally very moderate, even in the few gold mines associated with uranium by-product, and do not warrant the type of regulatory attention normally applied to nuclear installations, or even to uranium mines. The continued imposition of strict nuclear regulatory requirements has caused severe financial hardship and threatens the survival of certain mining operations, while seemingly having little or no health benefit to workers or the public. With the development of modern, comprehensive mine health and safety legislation, a more appropriate, effective, and far less costly vehicle for controlling radiation hazards in mines now exists, utilizing the resources of the Mine Health and Safety Inspectorate. This approach is now being proposed, in the drafting of new legislation, as constituting a better alternative to the nuclear regulation of mines.

1. BACKGROUND

The history of uranium production in South Africa dates back to 1944, when the mining industry undertook to assist in investigating the low-grade uranium mineralization found in association with gold in the Witwatersrand mines, as part of efforts to acquire uranium for the Manhattan Project. Early samples were of a much higher uranium content than the average ore mined, but even then they were of a grade that was regarded as uneconomic by the uranium producers at the time, leading to a period of intense investigations into extraction techniques. Leaching experiments were started in 1946, followed by the commissioning of the first pilot plant on a gold mine in 1949.

Since the opening of the first production plant at the West Rand Consolidated gold mine in 1952, about 180 000 t of U_3O_8 has been produced as a by-product of gold. The average U_3O_8 grade from a particular conglomerate formation on a gold mine varies from 0.001% to 0.078%, while the overall distribution of mine average grades is as shown in Figure 1. The average U_3O_8 grade for all goldfields in the Witwatersrand Basin is 0.013%, and the current average recovery grade is 0.0184% [1].

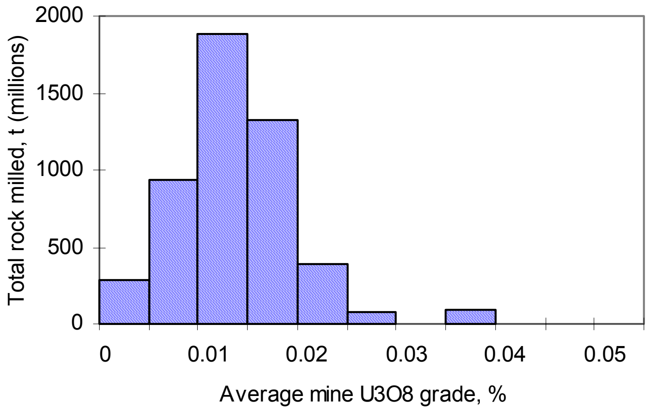

FIG. 1. U_3O_8 grades on South African gold mines.

Uranium has also been produced as a by-product of copper since 1971 at an average U_3O_8 grade of only 0.004%, and from a primary uranium mine that was operated for a short period in the early 1980s, but these operations account for only about 3% of total uranium production.

Figure 2 shows how South African U_3O_8 production has varied since its inception, in relation to the world market price. A peak production of 7295 t, representing 16% of world production, was reached in 1980 when there were 18 uranium plants in operation, putting South Africa among the top three producers.

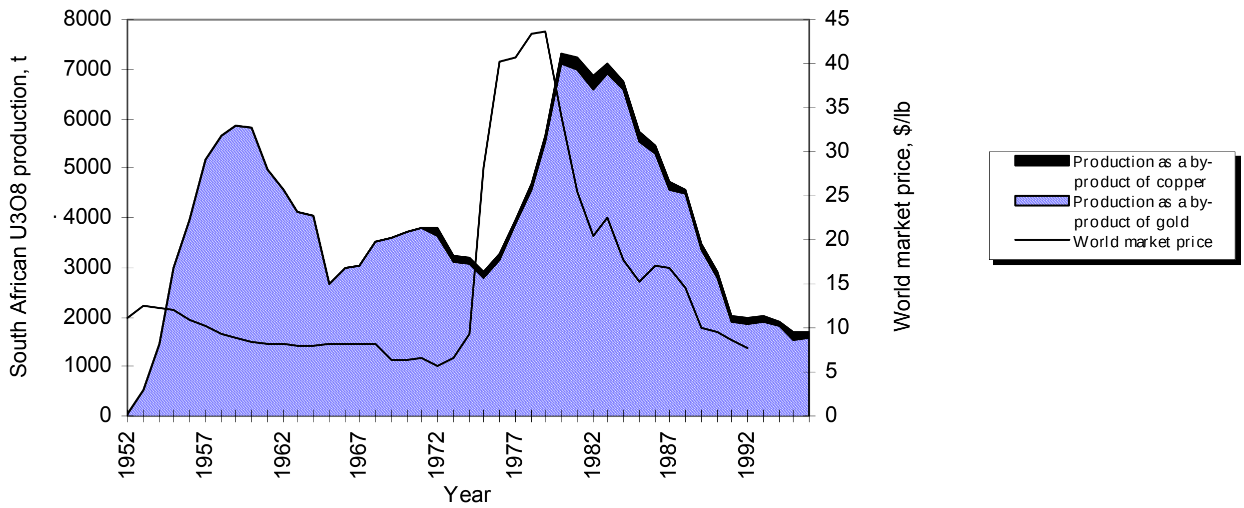

FIG. 2. South African uranium production [1].

Thereafter, with the fall in price, production declined steeply and all but 4 uranium plants were closed down. Present annual production, at less than 2000 t, represents only 4% of world production. In 1980, 34% of all gold reef mined was treated to extract uranium. Today that figure is below 10%.

2. DEVELOPMENT OF THE NUCLEAR INDUSTRY IN SOUTH AFRICA

The huge growth in uranium production prior to 1980 went hand-in-hand with a general growth of the nuclear industry in South Africa. In 1965, South Africa’s first research reactor was commissioned, and in 1967, when the first signs emerged of an ordinary commercial demand for uranium as distinct from a strategic demand, the mining industry established its own uranium sales organization. Also during the 1960s, intensive research was carried out into a new process for uranium enrichment, although it was not until 1987 that semi-commercial production started. In 1984, the first nuclear-generated electricity was produced, with the commissioning of the Koeberg nuclear power station, and in 1986 a low- and intermediate-level radioactive waste disposal facility at Vaalputs received its first consignment.

These developments contributed to the establishment of a sophisticated and comprehensive nuclear industry in South Africa, of which the mining industry, as a major supplier of uranium at the time, was regarded as a key component.

3. DEVELOPMENT OF THE NUCLEAR REGULATORY SYSTEM IN SOUTH AFRICA

In 1948, following the repeal of two War Measures that had placed controls over activities involving uranium in the hands of the Prime Minister and a few highly placed government, scientific and mining officials, all nuclear matters became the responsibility of the Atomic Energy Board (AEB), which was established in terms of the Atomic Energy Act of 1948. In 1963, the construction of a research reactor prompted the promulgation of the Nuclear Installations (Licensing and Security) Act, in terms of which the AEB became responsible for regulating nuclear safety. In 1969, the AEB established a licensing branch in anticipation of South Africa's first nuclear power station.

In 1982, the Nuclear Installations (Licensing and Security) Act and the Atomic Energy Act were consolidated into the Nuclear Energy Act of 1982, simultaneously creating the Atomic Energy Corporation (AEC) (formerly the AEB) and the Council for Nuclear Safety (CNS). However, operational aspects of nuclear regulation remained with the licensing branch of the AEC until 1988, when all aspects of nuclear safety regulation were placed with the CNS, which now had the power to operate independently and employ its own staff. Bearing in mind the political isolation of South Africa at the time, it was not surprising that the 1982 Nuclear Energy Act continued to display the characteristics of earlier legislation, which were formulated around the strategic aspects of uranium and the need for secrecy in the interest of national security.

Although South Africa's political situation has since changed dramatically, nuclear regulation under the present Nuclear Energy Act of 1993 is still to a great extent based on the original provisions contained in the 1982 Act, thus perpetuating the style of nuclear regulation that was characteristic of a past chapter of South Africa's history in which the exploitation of uranium-bearing ore was regarded as an integral part of a nuclear industry spanning the full nuclear fuel cycle. It is not surprising, therefore, that the mining industry has become, in the minds of many, synonymous with the nuclear industry and has found itself included in the system of nuclear regulation established for nuclear installations. This situation persists, despite the fact that the exploitation of uranium ore has in the meantime dwindled to minimal levels and now represents an almost insignificant contribution to mining industry revenue (0.7% of gold sales, 0.3% of total mineral sales). Moreover, with the closure of all enrichment operations and the availability of enriched uranium from elsewhere, the little uranium that is still produced plays no part in the South African nuclear industry.

4. APPLICATION OF NUCLEAR REGULATION TO MINES

Soon after the establishment of the CNS as a fully independent nuclear regulator in 1988, attention was turned to the regulation of radiation hazards associated with mines exploiting uranium as a by-product, although workers in uranium plants had hitherto always been subjected to routine urine monitoring.

It was the stated intention of the South African government at this time that control over radiation hazards in mines should be exercised ultimately under mining law, rather than under the 1982 Nuclear Energy Act. However, because the mining legislation, and possibly also environmental legislation, needed to be amended, it was decided as an interim measure that the mining activities concerned would have to be licensed by the CNS in terms of the 1982 Nuclear Energy Act. Once the licences had been issued, the plan was for control to be exercised jointly by the CNS, who would determine standards and the provisions necessary to meet those standards, and the Government Mining Engineer who would, by appropriate inspection programmes, ensure compliance with the requirements.

What transpired, however, was rather different. Nuclear regulatory control over mines became the sole responsibility of the CNS, and has remained so ever since. Mines that produced, or had previously produced, uranium as a by-product were from 1990 onwards required to apply for nuclear licences. This process was soon extended to all gold mines, regardless of whether they had produced uranium, and eventually to other mines as well. To date, 44 nuclear licences have been issued to mines - 38 of them to gold mines - of which only 4 relate to mines that still produce uranium as a by-product.

Regulations in force under the 1993 Nuclear Energy Act define the scope of nuclear regulatory control as follows:

(1) The provisions of the Act apply to radioactive material in which the activity concentration of any radionuclide is 0.2 Bq/g or more.

(2) The CNS may, at its discretion, allow human activities involving such radioactive material to be carried out without a nuclear licence, but only if one of the following two criteria are met:

  (a) the activity concentration of the material and the total activity involved over one year must be less than 100 Bq/g and 10 000 Bq respectively, or

  (b) the radiation dose that persons may accumulate must be less than 1 mSv (presumed to be over a period of one year).

On the basis of these criteria, the Nuclear Energy Act applies to a wide variety of mining and ore processing operations. In terms of phasing-in regulations, nuclear licensing has already been implemented on gold, mineral sands and phosphate operations. From April 1999, the scope of implementation could well be extended to other types of mines. Exemption on the basis of activity will not be possible because the value of 10 000 Bq will always be exceeded over a year of operation. Exemption on the basis of dose may be possible in open pit mines, but may be difficult to obtain in the case of underground mines because of doses due to radon progeny. Assuming an equilibrium factor of 0.4, occupational exposure to radon progeny will exceed the prescribed value of 1 mSv per year if the radon concentration exceeds 160 Bq/m^3. This is a very moderate concentration that is found in a large number of homes, and could easily be exceeded in underground workplaces even where the levels of uranium mineralization are not elevated. The IAEA reference level of 1000 Bq/m^3 [2], below which radon is not included in occupational exposure, is not recognized in South African nuclear regulation.

5. NUCLEAR REGULATORY REQUIREMENTS ON MINES

The Nuclear Energy Act imposes *inter alia* the following requirements on mines which fall within its scope, and for which exemption from licensing cannot be obtained:

- An authorization must be obtained from the CNS, and such authorization can only take the form of a nuclear licence.

- Nuclear licence fees are payable to the CNS, and the amounts of such fees are determined by the CNS.
- A nuclear licence is subject to any conditions deemed necessary or desirable by the CNS for the purpose of safeguarding persons from nuclear damage.
- Mines are subject to the special regime of strict liability and compulsory security normally applied to nuclear installations. It should be noted that this is in direct contradiction with practice adopted in other countries, as quoted by the OECD/NEA [3]:

  "The special liability regime for nuclear activities outlined above applies only to "nuclear installations" in which highly dangerous processes are carried on ………

  In the case of other uses of nuclear materials, such as radioisotopes used in medicine and industry, the risk is much lower and can be easily accommodated within the regular civil liability system. Similarly, uranium mining and milling is not covered by the special regime, as there is no danger of "criticality" or a sudden accident and the level of radioactivity is fairly low."

- Mines are subject to similar requirements as those imposed on nuclear installations in respect of duties in case of nuclear accidents.

6. CONDITIONS OF MINE NUCLEAR LICENCES

Site-specific nuclear licence conditions imposed on South African non-uranium mines are similar in nature to those for uranium mines in developed countries. Aside from whether it is even necessary or appropriate to apply the system of nuclear licensing, the specific details of the licence conditions imposed are of concern with respect to their practicality, their effectiveness in relation to the cost implications, and their consistency with current IAEA standards. These concerns can be grouped into the following two broad areas.

6.1. Problems with the prescriptive approach

The licence conditions tend to be prescriptive in nature, leaving little to the discretion of the operator. Examples include conditions relating to waste management programmes, environmental surveillance, effluent control, training programmes, medical surveillance, reporting procedures, analytical methods, monitoring procedures, instrumentation, and quality management. Almost everything has to be formally approved by the regulator, leading to a costly and time-consuming process and representing an unjustified and unwelcome involvement of the regulator in the operator's management functions. Instances have arisen where the rigid enforcement of detailed procedures has resulted in risks being increased rather than reduced. This approach has discouraged rather than encouraged the development of the necessary safety culture on mines, and has tied up huge resources on the mines and within the regulatory system, all of which have to paid for by the operator.

6.2. Problems with numerical limits

Various numerical limits imposed through mine nuclear licence conditions are of concern because they are out of date, inconsistent with each other and with international practice, and/or selected on a highly conservative rather than realistic basis. In some cases, this has led to compliance problems that threaten the continued survival of mines (see Section 9 below).

6.2.1. Occupational dose limit

The occupational dose limit imposed is 50 mSv/a which is, of course, no longer the limit recommended internationally. The derived limits for inhalation of radon progeny and dust are based not only on this old dose limit, but also on dose conversion factors that have been superseded. Using current IAEA dose conversion factors [2] and assuming, for dust inhalation, a lung solubility class S and an Activity Median Aerodynamic Diameter (AMAD) of 5 μm, the ALIs imposed through mine nuclear licences correspond to a wide variety of effective doses, none of which are in accordance with the internationally accepted 5-year average annual dose limit of 20 mSv [2], as shown in Table I.

TABLE I. OCCUPATIONAL LIMITS IMPOSED THROUGH MINE NUCLEAR LICENCES

Type of exposure	ALI imposed	Current IAEA dose conversion factor	Corresponding effective dose
External gamma	---	---	50 mSv
Inhaled radon progeny	17 mJ h m^{-3}	1.4 mSv per mJ h m^{-3}	23 mSv
Inhaled U ore dust, decay chain in equilibrium	1700 Bq	0.0055 mSv/Bq	9 mSv
Inhaled U concentrate	1500 Bq	0.0062 mSv/Bq	9 mSv

6.2.2. Public dose limit

The limit on effective dose for the critical group of members of the public, arising from operations at, or effluent discharges from, the mine is 0.25 mSv/a. This value was derived by the regulatory authority by designating the maximum acceptable risk to an individual as being 5×10^{-6} per year and assuming a risk factor of 2×10^{-2} per Sv which, of course, is quite different from the approach adopted by the ICRP [4]. The critical group may also receive doses from other mines in the vicinity, but experience has shown that such doses are likely to be very small in comparison. Thus, the public dose limit of 0.25 mSv/a imposed through mine nuclear licences, notwithstanding its applicability being limited to doses from a single practice, is far more restrictive than the internationally accepted value of 1 mSv/a [2].

6.2.3. Surface contamination limits for release of materials and equipment

Materials and equipment are released from mines for reuse, recycling or repair. The limits imposed on surface contamination of materials and equipment released unconditionally from mines are:

⇒ 0.04 Bq/cm^2 for alpha emitters,
⇒ 0.4 Bq/cm^2 for beta emitters, and
⇒ 0.5 μSv/h for gamma radiation.

Firstly, measurements of alpha radiation from the surfaces of typical materials and equipment released from mines are likely to be meaningless because the irregular geometry prevents the full surface of the detector from being positioned sufficiently close to the contaminated surface, and adequate counting times for assessing compliance with such a low activity level are too long to be practicable.

Secondly, the values for alpha and beta radiation appear to be the most conservative of those adopted anywhere in the world. Maximum surface contamination values quoted for seven OECD countries, obtained from a cursory scan of available literature, ranged from 0.05 to 20 Bq/cm^2 (alpha), and from 4 to 10 Bq/cm^2 (beta).

These unconditional release levels cannot practicably be complied with when it comes to the recycling of scrap steel and the repair of equipment at external repair facilities. Mine licence conditions require that materials and equipment contaminated above unconditional release limits may only be released to facilities that are themselves subject to nuclear licensing and that, even then, contaminated items associated with certain metallurgical processes are prohibited altogether from leaving the mine.

6.2.4. Activity limit on radioactive waste disposal

Waste rock and tailings account for all but one ten thousandth of a percent of the radioactive waste generated annually on South African gold mines. The remainder consists mainly of plant residues that are removed during maintenance, typically in the form of sludges, scales, and contaminated steel, rubber, plastics and refractory material that cannot be recycled. Some of the scales have an activity concentration of up to 3 orders of magnitude greater than those of the tailings, but because the quantities are so small, the total activity is negligible in comparison. It is normal international practice to dispose of such material in the tailings whereupon it can no longer pose any significant hazard over and above that posed already by the tailings [5], but licence conditions on South African mines prohibit such a practice if the activity of the material exceeds 1000 Bq/g, even if it is diluted and dispersed in the tailings. No other approved disposal route exists, so the material exceeding 1000 Bq/g has to be stored indefinitely on the mine, resulting in additional costs being incurred to control the ongoing potential hazard, even after mining operations have ceased.

7. RADIATION HAZARDS ASSOCIATED WITH SOUTH AFRICAN GOLD MINES

7.1. Occupational exposures

An extensive survey of underground occupational exposures in South African gold mines was conducted in 1993/4, when exposures to radon progeny inhalation, external gamma radiation, and ore dust inhalation were measured on 21 underground gold mines [6]. At the time, those 21 mines employed 152 000 underground workers, representing 60% of the total underground workforce in the gold mining industry. Since then, additional measurements have been made, as required in terms of nuclear licence conditions, but the dose calculations have not yet been verified in terms of the dose conversion factors used (see Section 6.2.1 above). Indications are that exposures have not generally decreased since 1993/4.

On the basis of the 1993/4 results, the average annual effective dose to underground workers was calculated to be 2.55 mSv, made up as follows:

⇒ average effective dose from radon progeny inhalation: 1.80 mSv,
⇒ average effective dose from external gamma radiation: 0.64 mSv, and
⇒ average effective dose from ore dust inhalation: 0.11 mSv.

It was estimated that 0.7% of the workplace locations covered by the survey were associated with exposures that, if sustained by the same worker for 2000 h, would give rise to a dose exceeding the internationally-accepted 5-year annual average dose limit of 20 mSv [2]. This issue is discussed further in Section 9 below.

Exposure to radon progeny is clearly the predominant contributor to total effective dose, although the concentrations are for the most part low. Figure 3 shows the distribution of radon gas concentrations, estimated from the radon progeny measurements assuming an equilibrium factor of 0.4. It can be seen that 87% of the sampling locations show radon concentrations below 1000 Bqm^{-3}, the IAEA action level for remedial action relating to chronic exposure to radon in workplaces [2].

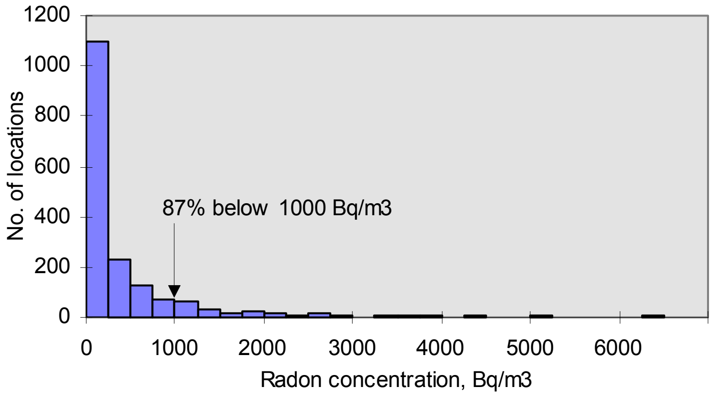

FIG. 3. Underground radon concentrations.

7.2. Public exposures

Although all potentially significant exposure pathways to the public have been considered, only three sources of exposure have been identified as warranting more detailed investigation. These are radon exhaled from mine tailings, waste rock piles and upcast shafts; radioactive contamination of surface and ground water; and the release of potentially contaminated materials and equipment from mines.

7.2.1. Radon from tailings, waste rock piles and upcast shafts

Over the past few months, radon concentrations in one of the largest gold mining regions have been modelled using the US EPA ISC3 dispersion model. The region contains 28 tailings dams, 20 waste rock dumps and 22 upcast shafts, and has four significant population centres, some portions of which are within a kilometre or two of some of these radon sources. The average uranium grade in this area is 0.020%, which is considerably above the industry average of 0.013%. Indeed, this region is the source of 87% of South Africa's current uranium production.

A weather station situated almost centrally within the region provided weather data over a full year at 5 minute intervals. For the purpose of the modelling exercise, conservative default values for radon source terms were used. For tailings dams, an exhalation of 1 Bq m^{-2} s^{-1} was chosen, whereas measurements mostly ranged from 10% to 40% of this value.

Incremental doses to members of the public living in the region were calculated from the estimated incremental indoor radon concentrations, assuming an occupancy of 7000 h/a and an equilibrium factor of 0.4. Because South African homes are well ventilated, an air exchange of 1 h^{-1} was assumed, from which it can be established that the indoor and outdoor incremental radon concentrations will be almost identical [7]. On this basis, a 1 Bq/m^3 increase in the concentration of outdoor radon will give rise to an additional dose of 17 μSv/a.

The results are shown in Table II. The population-weighted mean incremental radon concentration was about 2 Bq/m^{-3}, giving a mean incremental dose of 34 μSv/a. The maximum incremental radon concentration was just over 7 Bq/m^{-3}, giving a maximum incremental dose of about 120 μSv/a.

TABLE II. INCREMENTAL RADON CONCENTRATIONS AND EFFECTIVE DOSES RECEIVED BY MEMBERS OF THE PUBLIC

	Incremental radon concentrations, Bq m^{-3}		Incremental effective doses, μSv/a	
	Minimum	Maximum	Minimum	Maximum
Large town	0.7	2.4	12	41
Small town 1	2.2	7.2	37	122
Small town 2	1.7	3.0	29	51
Mine residential area	3.5	4.6	59	78

As a check on the modelling results, a portion of the same mining region was modelled with the ISC3 dispersion model, with the radon sources limited to 7 tailings dams, and then modelled by an independent consultant using the IMPACT™ software developed in Canada. The results, shown in Figure 4, are in quite good agreement.

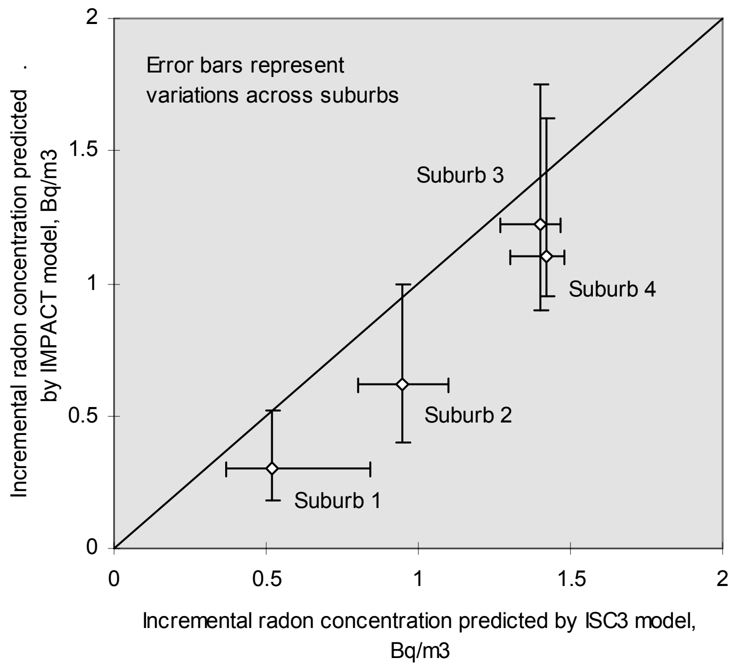

FIG. 4. Comparison of incremental radon concentrations determined independently using different modelling software.

To further confirm that incremental radon exposures to the public from gold mining facilities are very low, thirty homes in the same mining region were monitored for radon. The average concentration measured was 49±16 Bq/m^{-3}. The national seasonally averaged indoor radon concentration, measured in 1991, is 50 Bq/m^{-3} [8], indicating that there is no significant elevation of radon concentrations in homes in the mining region concerned.

7.2.2. Ingestion of contaminated water

Water samples were collected at 41 strategically selected locations (surface and ground water) throughout a major gold mining region over a period of a year, initially on a weekly basis and later at monthly intervals. The samples were analysed for all radionuclides having significant dose conversion factors and the annual ingestion doses were calculated assuming, conservatively, that the water formed the sole source of drinking water for humans. Figure 5 shows that the resulting ingestion doses were mostly less than 100 μSv/a.

7.2.3. Release of potentially contaminated materials and equipment

For unconditional release, the highly restrictive release levels specified in Section 6.2.3 above ensure that doses received by members of the public are well within the range of triviality. Under arrangements for conditional release, the mining industry dispatches annually 60 000 t of scrap steel for recycling by melting at a nuclear licensed facility, where it is mixed at random with 240 000 t of uncontaminated steel from other sources. In order to convince the regulatory authority that this would not give rise to unacceptable radiation exposures:

- surface contamination measurements on a huge number of scrap steel items were made, from which a representative lognormal distribution was derived;

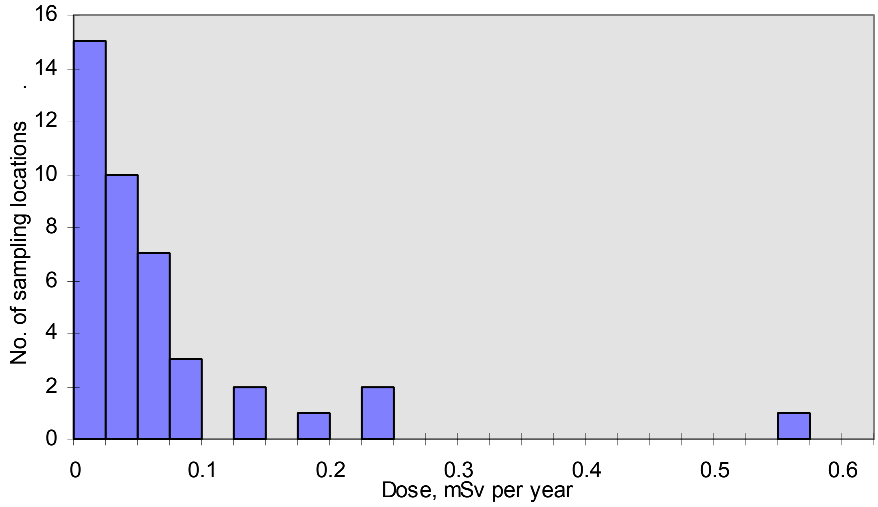

FIG. 5. Effective dose from the ingestion of water contaminated by gold mining activities, assuming continuous use for drinking purposes.

- a full scale melting experiment at the facility was carried out using 35 t of mine scrap, specially selected for the highest activity levels, to determine the partitioning of several key radionuclides in the melting process and to establish dust activity concentrations at all workstations;
- a detailed occupational dose assessment was carried out for all groups of workers involved in the recycling process; and

- a detailed public dose assessment was carried out for all groups of individuals exposed to the steel produced from the recycling process.

The results of this investigation revealed the following:

(a) the maximum dose to any worker was 4 μSv per year, and

(b) the maximum dose to any member of the public exposed to the steel produced was between 1 μSv and 4 μSv per year.

In the case of repairs to potentially contaminated equipment, a detailed study of several representative repair facilities was carried out, with respect to gamma radiation, radon and airborne radioactive dust. Levels of radiation were found to be indistinguishable from natural background.

8. ECONOMIC IMPACTS OF NUCLEAR REGULATION OF MINES

The costs of compliance with nuclear licence conditions on mines are not easy to determine, because they tend to be spread across a variety of cost centres. As mines gained experience in fulfilling regulatory requirements, attempts were made to estimate in advance what the costs were likely to be. The results of these estimations (expressed as total mining industry costs in South African Rand) were as follows:

- Once-off costs (totalling R124 000 000):

º Initial hazard assessment and establishing radiation protection infrastructure	R85 000 000
º Equipment decontamination facilities	R25 000 000
º Special changehouse facilities	R14 000 000

- Annual costs (totalling R45 000 000):

º Licence fees	R11 000 000
º Additional staffing and instrumentation	R34 000 000

Assuming that the once-off costs are spread over six years, these estimates would give a total annual cost to the 44 nuclear licensees in the mining industry of R66 million (about US$10 million). The average annual cost per licensee would therefore be R1.5 million (about US$240 000).

Recently, data on actual costs incurred were obtained for 12 mining operations. The average cost per operation, shown on a year-by-year basis in Figure 6, has climbed to just under R2 million per year, a figure that is in good agreement with the earlier estimate of R1.5 million. Staff and consultants accounted for the largest portion of the total (more than half).

Not included in the above costs are the hidden costs associated with the repair of equipment and recycling of materials off the mine. Because such materials are potentially radioactively contaminated, the system of nuclear regulation is extended to off-mine repair and recycling facilities, even though the radiation doses received by workers and the public have been shown to be insignificant (see Section 7.2.3 above).

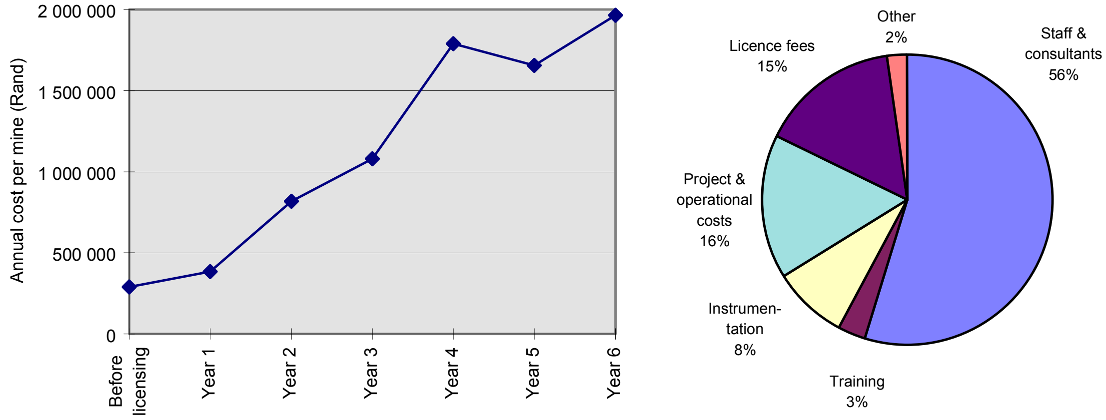

FIG. 6. Average annual cost per mine of compliance with nuclear regulatory requirements, based on actual expenditures for 12 operations.

The costs of nuclear regulation of these facilities is eventually borne by the mines through higher repair costs and, to a lesser extent, lower prices paid for scrap metal. Estimates put the annual figure at R22 million, or an average of R500 000 per mine.

To appreciate the impact of these costs, the current financial situation of the mining industry, particularly the gold mining industry, needs to be considered. Since 1980, when the gold price was at its peak, the gap between working revenue and working costs has narrowed dramatically, as shown in Figure 7. As profits plunged with the fall in gold price, a point was reached in 1986 where the industry started to shed jobs in order for mines to remain in operation (Figure 8). Since 1986, some 200 000 jobs have been lost, and the trend continues. Under these circumstances, where there is no control over the world market price of the product, strict cost control becomes paramount for survival. Although health and safety cannot be compromised, mines are forced to ensure that health and safety expenditure is as effective as possible. There are serious concerns that much of the current expenditure on compliance with nuclear regulation is not providing real health benefits, and that such expenditure could be more beneficially used to help ameliorate the significant non-radiological hazards associated with deep level gold mining.

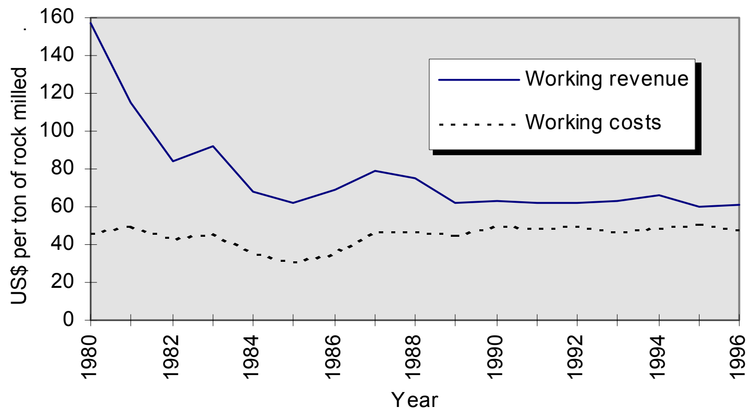

FIG. 7. Working revenue and costs on South African gold mines [1].

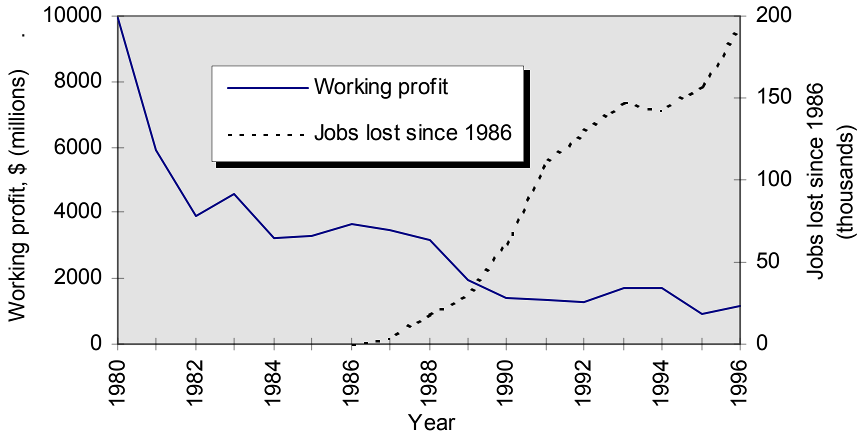

FIG. 8. The fall in profits and resulting job losses on South African gold mines [1].

Some gold mines are already in a loss situation, or are so close to making a loss that they are unable to make sufficient capital investment to ensure their continuing survival. Some of these mines have already been forced to withhold nuclear licence fees or to withdraw their financial security, and thus run the risk of prosecution under the Nuclear Energy Act. For such mines, the point is being reached where the cost of nuclear regulation represents a real threat to jobs. With unemployment in South Africa approaching 40%, workers losing their jobs on the mines have almost no hope of ever finding employment again.

9. PROBLEMS WITH DOSE LIMIT COMPLIANCE

Although radon concentrations are generally low, a small number of workplaces are associated with exposures that, if sustained by the same worker for 2000 h, would give rise to a dose exceeding the internationally-accepted 5-year annual average dose limit of 20 mSv [2]. One particular section of a gold mine has become a contentious issue in this regard, due to the following combination of factors:

(a) the section is more than 40 years old, and was not designed in accordance with present-day ventilation standards;

(b) the section has 50 km^2 of worked out areas which are difficult to seal off effectively;

(c) there is entry of methane into the workings which, if the area were sealed off, would build up to dangerous levels; and

(d) the gold reef is very wide, but is only payable in its centre portion; unpayable reef therefore has to be left behind in the hangingwall and footwall, representing an additional source of radon in the back areas due to residual uranium mineralization.

Several radon monitoring programmes, including personal dosimetry programmes, have been carried out since 1993, in conjunction with a series of attempts to reduce radon concentrations (with limited success). Figure 9 shows the results of the largest of these personal dosimetry programmes, in which about 600 track etch radon progeny dosimeters were deployed. The average annual effective dose, projected from the one-month deployment period, was about 16 mSv, with a maximum value of 56 mSv.

With the natural mobility of workers, it would seem unlikely that, in terms of IAEA dose limitation standards [2], the single-year limit of 50 mSv would be exceeded, and it is questionable whether any worker would receive a dose of more than 100 mSv in 5 years. In any case the section will be mined out in 2 years, at which time new ore reserves will have been accessed elsewhere, allowing the workers to be transferred.

However, in terms of South African dose limitation standards, the situation is deemed by the regulatory authority to be already in violation of licence conditions and, unless major reductions in radon concentrations can be achieved, it is understood that the section will ordered to close, putting 1200 workers out of work.

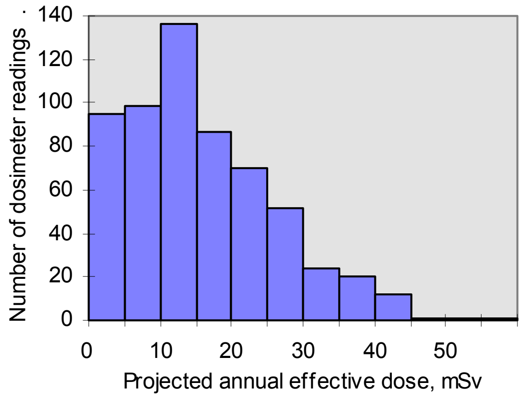

FIG. 9. Annual doses projected from the one-month deployment of personal dosimeters in an underground mine section with high radon concentrations.

10. THE WAY FORWARD

It is now nearly ten years since the decision was taken to bring radiation hazards in South African mines under a formal system of regulatory control. In the meantime, new improved legislation has been introduced - the Mine Health and Safety Act of 1996 - that is dedicated to the control of all health and safety hazards in mines. This Act contains all the necessary provisions to protect the health and safety of mineworkers and members of the public against radiation hazards, in accordance with IAEA and ILO requirements, such as: identification of hazards; assessment and minimization of risks; establishment of mandatory codes of practice; participation of employees through health and safety committees on mines; appointment of qualified staff; training; monitoring of health and safety conditions; medical surveillance; record keeping; supply of adequate health and safety equipment; enforcement of health and safety measures; investigations and inquiries to improve health and safety; and promotion of a culture of health and safety, and of co-operation and consultation between the State, employers, employees and their representatives.

Moreover, because the Mine Health and Safety Inspectorate, established in terms of the 1996 Mine Health and Safety Act, already possesses most of the necessary enforcement infrastructure, the necessity for a separate and additional infrastructure within the CNS - and the huge cost to mines that this entails - becomes highly questionable.

11. CONCLUSIONS

Even if there once had been valid arguments for including some South African mines in the system of nuclear regulation, such arguments were in any case founded on events in a past chapter of South Africa's history, and have no relevance today. The exploitation of uranium as a by-product on South African mines has dwindled to minimal levels and no longer has any real connection with the nuclear industry; yet the system of nuclear regulation of mines, paradoxically, has been expanded to the point where 44 nuclear licences have now been issued to mines, only 4 of which relate to mines that still produce uranium as a by-product.

It has been argued by some that the very strict regime of nuclear regulatory control is required on mines because of the possibility of workers and members of the public receiving unacceptably high radiation doses. Extensive monitoring and dose assessment exercises have failed to provide any support for this argument, as indicated by the following findings:

(a) Because of the very low levels of uranium mineralization, the radiological hazards to underground workers on South African gold mines are limited mostly to the inhalation of radon progeny. Measurements indicate that little more than 1 in 10 underground workplaces exhibit radon concentrations exceeding the IAEA action level of 1000 Bq/m^3 for remedial action relating to chronic exposure to radon. Although the possibilities exist of a worker exceeding IAEA dose limits, such possibilities appear to be limited to less than 1% of underground workplaces, and to the unlikely situation of a worker being deployed, by chance, at the point of maximum radon concentration continuously for more than 2 years.

(b) Radiological hazards to the public may arise through the inhalation of radon from tailings, waste rock and upcast shafts, or possibly through the ingestion by informal communities of untreated water contaminated by gold mining activities. However, these exposure pathways generally give rise to annual doses of less than 100 μSv/a, or one tenth of the public dose limit, and thus border on what would be regarded internationally as trivial.

(c) Radiation doses arising from the release from mines of potentially radioactively contaminated materials equipment for recycling or repair have been shown to be insignificant.

Despite these findings, the system of nuclear regulation has continued to be applied to South African mines in a rigid and prescriptive manner, using interpretations of IAEA standards that lack consistency, and that are at best highly conservative and at worst contradictory. Furthermore, special measures associated with the possibility of accidents with catastrophic consequences, such as the imposition of a strict regime of liability for nuclear damage and the associated requirement of compulsory security, have been applied to mines even though such measures are intended only for nuclear installations.

The impact of nuclear regulation on South African mines, particularly as a result of the desperate financial situation faced by many gold mines, has been out of all proportion to any health benefit that might have been derived. Indeed, there is no evidence to suggest that any real reductions in doses have been achieved, radioactive waste management problems have been created rather than solved, and the prescriptive approach to regulation has discouraged rather than encouraged the development of the necessary radiation safety culture on mines.

In straight financial terms, the average cost to a licensed mine has climbed to nearly R2 million per year, with some mines now risking prosecution because they cannot meet their regulatory obligations without their survival becoming threatened. The jobs of 1200 workers on one mine section are in jeopardy because the section is deemed to be in violation of dose limitation requirements on the basis of spot measurements and the one-month deployment of personal dosimeters, rather than on 5 year average doses as recommended by the IAEA.

South African nuclear legislation, and the nuclear regulatory system that it supports, is in need of revision not least to enable it to reflect modern democratic principles of accountability, transparency and public participation - there is no longer any need for the legislation to be framed around secrecy requirements and the strategic uses of uranium. In proceeding with such revision, the opportunity should be taken to ensure that the application of nuclear regulation, and in particular the system of nuclear licensing, is limited to those areas for which it is appropriate. Recent developments in mine health and safety legislation now provide a much more appropriate and effective vehicle for the regulation of radiation hazards in South African mines, and have dispelled any remaining arguments for retaining the old system of nuclear regulation of mines.

It is gratifying to note that new nuclear legislation drafted recently by the government reflects this approach, and it is to be hoped that this will soon find its way into the statute books.

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TRANSPOSITION OF ICRP–60 RECOMMENDATIONS INTO FRENCH URANIUM MINING REGULATION

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Abstract

Directive 96/29/Euratom, drawn up from recommendations of the ICRP 60, must be transposed into French legislation before 13 May 2000. For the French uranium mining sector, two ministerial decrees, one for workers, the other for the environment, must be modified to take account of the new European rules. These modifications entail new statutory limits either for the workers, or to characterise the radiological impact on the environment. For the workers, the implementation since 1980 of a policy of optimising radiation protection in French mines enables us to envisage that these limits will be respected. For the environment, the application of new limits involves a new approach for the assessment of public doses, with the precise definition of critical groups and their realistic exposure scenario.

1. INTRODUCTION

The recommendations of the ICRP 60 were used by the European Community to draw up the 96/29 EURATOM directive, fixing the basic standards relating to the protection of the health of the population and of the workers against the dangers resulting from ionising radiation.

This directive must be transposed into French legislation before 13 May 2000. An interministerial committee was established by the Prime Minister of France to prepare this transposition, which involves extensive revision of existing texts, including those which govern the radiological monitoring of workers and of the environment of uranium mining sites.

This interministerial committee includes the seven ministries concerned, which are Health, Employment, Industry, the Environment, Transport, Research and Agriculture.

A technical steering committee assisted by groups of experts is responsible for drawing up drafts of texts to be submitted to the Interministerial Committee which will decide the option to be retained in the texts.

At the present time, the architecture of the texts associated with the transposition of Directive 96/29 is being organised into a structure composed of five general texts stating the principles of protection against ionising radiation, the protection of workers and the protection of the population, the accidents and emergencies and the administrative procedures, as well as more specific ministerial decrees in certain fields such as the mining sector.

2. THE RADIOLOGICAL MONITORING OF WORKERS IN THE MINING SECTOR

2.1. Existing regulations for French uranium mines

The recommendations of the International Commission of Radiological Protection (ICRP N°. 26 and derivative publications) which were adopted by the European directives of 15th July 1980 and 3rd September 1984, were adopted into French legislation by a ministerial decree

(decree N° 98–502 of 13th July 1989) introducing requirements for the protection of workers against ionizing radiation into the Mining Code.
This regulation has been in force since 20th January 1990 in all French underground and open-pit mines and their associated mills.

The main technical characteristic of this regulation is that the exposure monitoring of personnel and the monitoring of the radioactive atmospheres at the work stations are handled using specifically laid down procedures and equipment.

For personal exposure monitoring, the French regulation requires the following systems to be implemented:

(a) individual dosimetry for workers likely to be subjected to an annual dose greater than 3/10th of the statutory limit;
(b) function dosimetry for checking operators likely to be subjected to an annual rate of exposure between 1/10th and 3/10th of the statutory limit.

Operators likely to be subjected to annual exposure of less than 1/10th of the annual limit are considered not to be exposed to ionizing rays and are not monitored. It is only necessary to check the working environment in order to ensure that the 1/10th of the statutory limit is respected.

These are the requirements applicable for radiological surveillance of French uranium miners [1]:

(a) individual dosimetry for operators working in underground mines, based on the use of equipment worn by operators during their working period enabling continuous measurement, during one month of the exposure to which each worker is subjected;
(b) function dosimetry for operators working in open-pit mines or mills, based on the use of equipment worn by a sample of workers representing different functions occurring in the operation concerned.

About the statutory individual limits, in uranium mines or mills we are in the situation of combined internal and external exposure, as the miner receives doses due to gamma rays (external exposure) and inhaling radioactive aerosol alpha transmitters (internal exposure) by mineral dust and short-lived radon decay products.

In addition, an annual limit taking into account the combined risks must be respected. For each worker, we must calculate the following formula:

$$TER = \frac{\gamma}{50\,mSv} + \frac{PAE\ Rn222}{20\,mJ} + \frac{PAE\ Rn220}{60\,mJ} + \frac{LLAE\ ore}{1700\,Bq\ alpha} + \frac{LLAE\ U}{30\,000\,Bq\ alpha}$$

with:
Gamma = the annual dose of external exposure in mSv,
PAE Rn222 and PAE Rn220 = potential annual inhaled alpha energy from short-lived decay products of radon 220 and 222 isotopes, in mJ,
LLAE = total activity of long-lived alpha emitters of the uranium chain, inhaled annually in Bq (ore or concentrates).

This formula is called the Total Exposure Rate "TER".

The limit of TER is 1 for 12 months running. The value of TER = 1 is equivalent to an effective dose of 50 mSv (with ICRP 32 and 47 dosimetric conversion coefficient).

2.2. The transposition of the European Directive for uranium mines

European directive 96/29 Euratom, recommends for occupational exposure a new limit on effective dose of 100 mSv in 5 years, not exceeding 50 mSv in any single year.

A new formula for the Total Exposure Rate would need to be taken into account, as follows:

$$TER = \frac{Hp}{50\,mSv} + \frac{PAE\ Rn222}{42\,mJ} + \frac{PAE\ Rn220}{127\,mJ} + \frac{LLAE\ ore}{5400\,Bq\ alpha} + \frac{LLAE\ U}{27\,000\,Bq\ alpha}$$

This TER should be lower than 2 over 5 years, not exceeding 1 per year.
This value of TER = 1 is here equivalent to an effective dose of 50 mSv.
The following equivalencies are considered here (Ref.: Annex III of the European Directive):

(a) for PAE Rn222 : 1.4 mSv ≡1 $mJ.m^{-3}.h$ or 50 mSv ≡ 42 mJ
(b) for PAE Rn220 : 1.1 mSv ≡ 1 $mJ.m^{-3}.h$ or 50 mSv ≡ 127 mJ
(c) for the uranium ore : $9.35.10^{-3}$ $mSv.Bq^{-1}$ alpha.

We consider here the whole of the long-lived alpha emitters of the uranium chains, assumed to be in radioactive equilibrium with an average lung clearance type M, an AMAD of 5µm and we suppose that no short-lived alpha emitter remains on the filter having sampled the aerosol inhaled.

— for the uranium concentrates dusts : $1.85.10^{-3}$ $mSv.Bq^{-1}$alpha.

With AMAD = 5 µm and a lung clearance type M.

The graphs in Annex I present the dosimetric situation of the underground mine and the processing plant of the Jouac Mining Company, the only mine in operation in France at the present time.

We can see that for the year 1997, the maximum effective dose recorded is equal to 15.8 mSv (i.e. a TER = 0.316) and that the average dose is equal to 6.5 mSv for the underground mine workings and 3.7 mSv for the processing plant.

We can therefore think that the implementation of the new regulations from the ICRP 60 ought not to introduce any discontinuity into the practice and results of the radiological monitoring of uranium mines in France. In fact, the efforts in risk prevention carried out by the mining company from 1984 up to now can guarantee that the new individual limits will be respected.

Unfortunately, when this new regulation comes into force, it will doubtless be difficult to see the result of these efforts inasmuch as French underground uranium mines, faced with the very depressed economic climate in the market for natural uranium, are doomed to disappear as the year 2000 approaches.

However, after the mining operations cease, there remains the problem associated with the environment and the radiological impact of the installations after they have been dismantled and the site reclaimed. It is on this second phase that the statutory constraints associated with the application of the recommendations of the ICRP 60 must now be analysed.

3. EVALUATION OF THE IMPACT ON THE ENVIRONMENT OF THE EXTRACTION INSTALLATIONS AND URANIUM PROCESSING PLANTS

3.1. The existing context of French regulations

Extraction and uranium ore processing operations significantly modify the natural radioactivity of a region, characterised in the beginning by important anomalies of uranium concentrations in the geological surroundings, at a relatively shallow depth and sometimes showing on the surface, but generally without any significant radiological impacts on the populations.

The transfer conditions of the associated radionuclides can be disturbed, notably in the neighbourhood of the surface storage of mining waste and solid processing tailings. For the local populations, this can result in an additional exposure to ionizing radiation according to different possible ways of transfer. A system for limiting the radiological risks caused by this additional exposure is necessary.

Since such a system will be dealing with chronic long-term exposure of low dose rate equivalent, and with no risk of accidental exposure to high doses, it can be based simply on the limitation of the annual dose equivalents of the population. However, this limitation requires a plan of action to confine the radionucleids at their sources of potential emission and to purify any possible liquid and gaseous waste. The effectiveness of these measures must be clearly demonstrated by a monitoring network of the releases, the environment and the exposure of the population.

This system for limiting radiological risks found its statutory expression in ministerial decree N° 90-222 of 9 March 1990, published in the Official Journal of the French Republic on 13 March 1990.

This decree was signed by the Prime Minister and the Ministers of Industry and of the Environment. It incorporates, under the title "*Ionizing Radiation*" of the General Regulations of Extracting Industries instituted by decree N° 80-331 of 7 May 1980, a part relative to the protection of the environment.

It specifies the conditions for the implementation of the radiological monitoring of the natural surroundings around the installations, as well as the constraints imposed on the management of radioactive products (storage of solid products and waste) to be respected by the extracting company. This is to ensure that the individual limits of additional exposure of the population are not exceeded and that the radiological impact on the environment is maintained at as low a level as can reasonably be expected.

For the evaluation of the impact, the ministerial decree N° 90-222 prescribes to calculate for the critical group the value of the following formula:

$$A.T.A.E.R. = \frac{\Delta\gamma}{5\ mSv} + \frac{\Delta PAE\ Rn222}{2\ mJ} + \frac{\Delta PAE\ Rn220}{6\ mJ} + \frac{\Delta LLAE\ ore}{170\ Bq} + \frac{\Delta Ra226}{7000\ Bqalpha} + \frac{\Delta U238}{2\ g}$$

with Δ equal to the different annual exposures due to the mining site with deduction of the initial natural exposure.

A.T.A.E.R. is the Added Total Annual Exposure Rate and must be less than 1 for characterising of an "acceptable impact" with the meaning of the decree.

The value of 1 for the ATAER is equivalent to an effective dose of 5 mSv according to ICRP 32 and 47 recommendations.

Based on field measures, ATAER is evaluated with the following parameters:

(a) time of exposure : 7000 hours per hour,
(b) inhaled flow rate : 0.8 m^3 of air per hour,
(c) drinking water : the only transfer pathway by ingestion, with 2.2 litres per day, with water of river immediately after dilution of releases.

for critical group of the public living in the immediate vicinity of the site.

This standard scenario is unrealistic and leads to over evaluate the public exposure but all the values of ATAER in the vicinity of French uranium sites are under the limit of 1 (or no effective dose of 5 mSv) and all the monitoring results of the networks check compliance with existing regulatory limits.

3.2. The transposition of the European directive

European Directive 96/29 Euratom lays down a limit of 1 mSv for the annual effective dose liable to be received by the public in the environment of an installation.

It also states that the doses resulting from a practice test should be evaluated as realistically as possible for the members of the public who characterise the population critical groups, in all places where such groups may exist and taking into account the effective pathways of radioactive substances towards these populations.

So, in this new context of regulations, the calculation methods used at present cannot be used, for they often consider fictitious people and unreal, extreme exposure scenarios to characterise the critical groups.

Studies are presently being carried out by mining companies to propose to the French authorities a realistic approach for the evaluation of the dose of the public in the environment of uranium mining sites, which would enable the provisions of title VIII of the Directive, describing the implementation of radiation protection for the population, to be respected.
For that, we consider:

Reference group: the members of the public (adult > 17 years) living in the close environment of the site, likely to be the most exposed because they live either down wind or in a low-lying topographical area (valley) or in direct view of the site or downstream of the hydrographical network.

Exposure scenario: exposure time – 7000 hours per year in the area under consideration of which: 3500 hours outdoors; 3500 hours indoors.

Exposure routes:
(a) external exposure outdoors;
(b) internal exposure due to the inhalation of long-lived alpha emitters present in aerosol dusts outdoors;
(c) internal exposure due to the inhalation of short-lived radon decay products, outdoors and indoors;
(d) internal exposure due to the ingestion of radionuclides of the uranium chain (U238, Ra226, Pb 210, Po210, Th230) with drinking waters (1.6 litres per day) and the food chain based on local products (with an annual theoretical consumption of : 30 kg of root vegetables; 20 kg of leaf vegetables; 40 kg of fresh fruit; 20 kg of poultry meat; 10 kg of fish; 70 litres of milk; 20 kg of cheese and butter).

All the exposures are expressed in mSv with the conversion factors given in the Annex III of European Directive.

For the whole of the exposure routes considered, networks of radiological measurements must be put in place to evaluate in a representative manner the radiological levels present. The limit of 1 mSv applies to the effective dose associated with the industrial impact, so the value added to the local natural level must be evaluated. Therefore from the value measured at each monitoring station the value corresponding to the natural level must be subtracted in order to find the contribution of “industrial” origin.

The problem appears easy to solve when a collection of radiological data is available from measurements taken before the work on the site began, and therefore characterising perfectly the natural surroundings to be taken into account for the assessment of the impact.

The problem becomes complicated when initial data do not exist (which is the case in the majority of old existing sites).

So, it appears reasonable to consider that for exposures linked to gamma radiation, to dusts and the ingestion of radionucleids, the natural level should be characterised by measurements carried out by monitoring stations installed in an environment geologically similar to the site under consideration and sufficiently far away to be unaffected by the site.

For exposures linked to radon222 and its decay products, the method which consists of taking a fixed value of the natural level measured in a distant environment to deduct it from the monitoring stations of the critical groups is no longer applicable, since spatial fluctuations of the natural level must be considered which are very often greater than the value of 1 mSv. So, the measuring network put in place must, for each station, enable the “industrial” component to be discriminated from the “natural” component on the value of potential alpha energy measured. It is then only the value of the “industrial” component which must be used to assess the contribution of radon222 to the effective dose of the reference group.

A discrimination method, founded on the differences in isotopic signatures characterised by the relative concentrations of radionucleids of the uranium and thorium chains, has been developed by ALGADE from continuous measurements taken by alpha site dosimeters used in atmospheric monitoring stations [2, 3].

In application of these new procedures enabling the provisions of the European Directive to be applied, evaluations have been made concerning the effective doses of reference groups in the environment of the 2 French mining sites belonging to COGEMA which are presently being reclaimed, (at Bessines-sur-Gartempe in the department of the Haute-Vienne, and at Lodève in the department of the Hérault). These evaluations have shown for the year 1997 levels of dose added to the natural level which are lower than 1 mSv, with the exception of two stations (out of the 15 considered) where the effective added doses are assessed at 1.21 mSv and 1.63 mSv (see Annex II).

These added doses are principally due to internal exposures linked to radon 222 and its decay products (between 60% and 70% of the assessed value).

Insofar as these 2 sites are still being reclaimed, it can be expected that when the final cover of the processing waste storage areas is complete, the levels of exposure associated with radon will decrease and enable the limit value of 1 mSv to be respected for critical groups taking into account.

4. CONCLUSION

For French uranium mining sites, the new statutory provisions which will be in force as of May 2000 in application of European Directive 96/29 Euratom, will bring to light additional constraints particularly as regards the environment and the radiological impact of sites for members of the public.

So, the application of new regulations will require:

(a) a realistic definition of the critical groups and their exposure scenario
(b) a precise definition of the natural background of the site under consideration
(c) a strict methodology for the monitoring of radiological levels in order to guarantee that the measurements are perfectly representative
(d) particular attention as to the choice of instruments for monitoring radon and its decay products in the atmosphere.

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Annex 1

Société des mines de JOUAC (COGEMA Group)

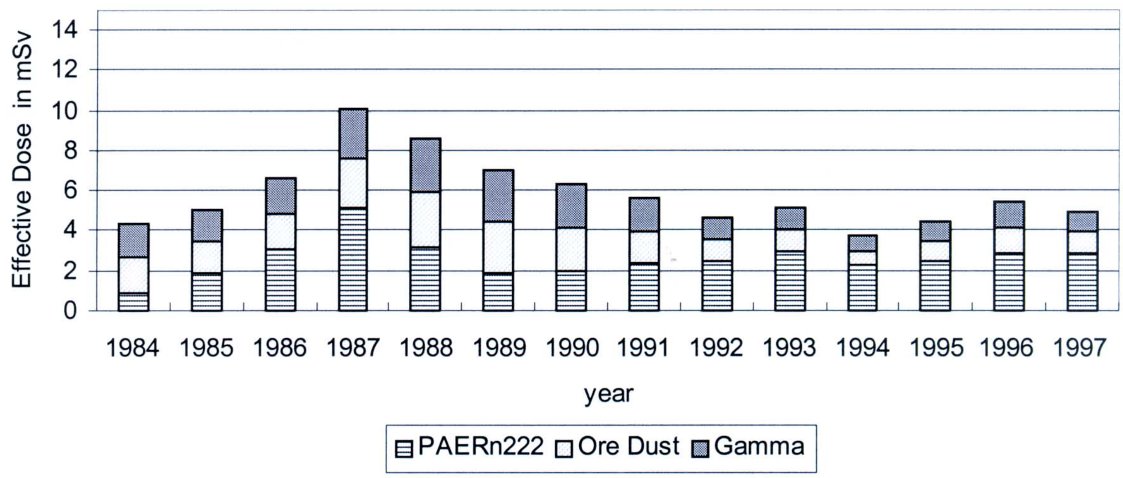
WORKFORCE DISTRIBUTION for 1997

Application of European Directive 96/29 Euratom

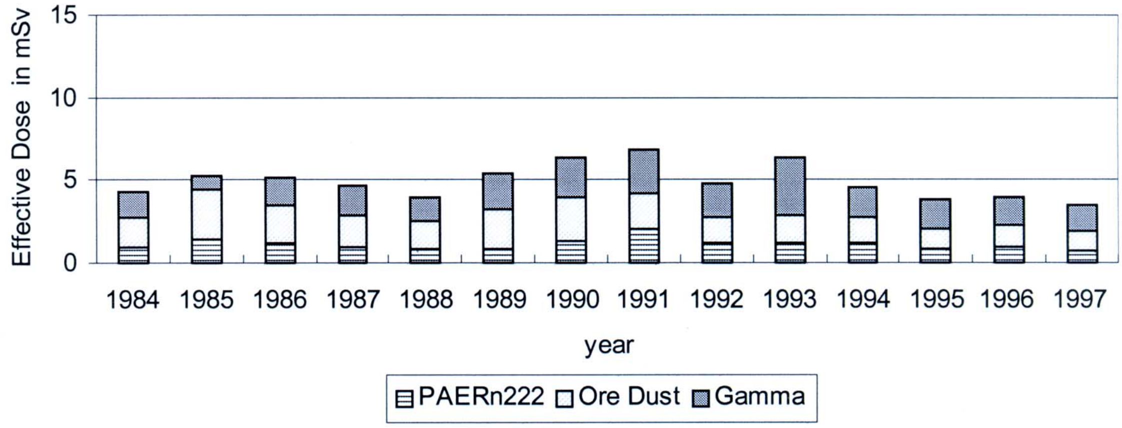
	EFFECTIVE DOSE IN mSv								number of assessed workers	COLLECTIVE DOSE homme.Sievert
	d<1	1≤d<5	5≤d<10	10≤d<15	15≤d<20	20≤d<30	30≤d<50	d≥50		
UNDERGROUND MINE	11	31	21	10	1				74	0,39
TREATMENT PLANT	5	32	2						39	0,11
TOTAL	16	63	23	10	1				113	0,5

$$\text{* Effective Dose} = 50\ \text{mSv} \times \left[\frac{\text{Gamma}}{50\ \text{mSv}} + \frac{\text{PAERn222}}{42\ \text{mJ}} + \frac{\text{PAERn220}}{127\ \text{mJ}} + \frac{\text{Ore dust}}{5400\ \text{Bq alpha}} + \frac{\text{Uranate dust}}{27000\ \text{Bq alpha}} \right]$$

EVOLUTION OF ANNUAL AVERAGE EFFECTIVE DOSE
for SMJ underground miners



EVOLUTION OF ANNUAL AVERAGE EFFECTIVE DOSE
for SMJ treatment plant workers



Annex 2

TABLE I. APPLICATION OF EUROPEAN DIRECTIVE 96/29 EURATOM — EVALUATIONOF ADDED EFFECTIVE DOSE BESSINES SITE (FRANCE) YEAR 1997 — LIVING AREA — 3500h INDOORS AND 3500h OUTDOORS

STATIONS	Gamma mSv	Δ gamma mSv	Dust mSv	Δ Dust mSv	PAE Rn222* indoors mSv	PAE Rn222* outdoors mSv	Drinking water mSv	Δ Drinking water mSv	Food chain mSv	Δ Food chain mSv	Added effective dose mSv
NATURAL BACKGROUND*	0,63	0,00	<0,04	0,00	0,00	0,00	0,28	0,00	0,31	0,00	0,00
LAVAUGRASSE	0,98	0,35	<0,04	0,00	0,18	0,10	0,46	0,19	0,37	0,06	0,52
LA CHATAIGNIERE	0,63	0,00	<0,04	0,00	0,76	0,44	0,46	0,19	0,55	0,24	1,63
ABATTOIR N° 66	0,74	0,11	<0,04	0,00	0,00	0,00	0,46	0,19	0,41	0,10	0,29
BESSINES la Poste	0,63	0,00	<0,04	0,00	0,00	0,00	0,46	0,19	0,41	0,10	0,29
HOTEL DU PONT	0,67	0,04	<0,04	0,00	0,07	0,05	0,46	0,19	0,41	0,10	0,41
LA CROIX DU BREUIL	0,63	0,00	<0,04	0,00	0,00	0,00	0,46	0,19	0,41	0,10	0,29
VILLARD	0,74	0,11	<0,04	0,00	0,23	0,26	0,46	0,19	0,41	0,10	0,78

Δ = the difference between the station's value and the natural background (mSv)

* = "industrial" radon

TABLE II. APPLICATION OF EUROPEAN DIRECTIVE 96/29 EURATOM — EVALUATIONOF ADDED EFFECTIVE DOSE HERAULT SITE (FRANCE) YEAR 1997 — LIVING AREA — 3500h INDOORS AND 3500h OUTDOORS

STATIONS	Gamma mSv	Δ gamma mSv	Dust mSv	Δ Dust mSv	PAE Rn222* indoors mSv	PAE Rn222* outdoors mSv	Drinking water mSv	Δ Drinking water mSv	Food chain mSv	Δ Food chain mSv	Added effective dose mSv
NATURAL BACKGROUND*	0,31	0,00	0,08	0,00	0,00	0,00	0,01	0,00	0,08	0,00	0,00
CAPITOUL	0,25	0,00	0,08	0,00	0,00	0,00	0,01	0,00	0,16	0,08	0,08
LES HEMIES	0,63	0,32	0,08	0,00	0,00	0,00	0,01	0,00	0,16	0,08	0,40
MAS LAVAYRE	0,42	0,11	0,08	0,00	0,00	0,00	0,01	0,00	0,16	0,08	0,19
St JEAN de la BLAQUIERE Auberge	0,39	0,08	0,08	0,00	0,00	0,00	0,01	0,00	0,16	0,08	0,16
St JEAN de La BLAQUIERE	0,53	0,22	0,08	0,00	0,00	0,00	0,01	0,00	0,16	0,08	0,30
St JULIEN	0,53	0,22	0,08	0,00	0,44	0,33	0,01	0,00	0,30	0,22	1,21
St MARTIN	0,49	0,18	0,08	0,00	0,19	0,16	0,01	0,00	0,18	0,10	0,63
LA SAUVAGEONNE	0,42	0,11	0,08	0,00	0,00	0,00	0,01	0,00	0,16	0,08	0,19

Δ = the difference between the station's value and the natural background (mSv)
* = "industrial" radon

COPING WITH NEW REGULATIONS — REPUBLIC OF NAMIBIA

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Abstract

In this paper we shall delineate the current regulatory set-up in Namibia i.e. legal framework, administrative arrangements for the management of uranium exploration, mining, milling and waste management. Uranium, mining plays a big role on the economy of Namibia. With changing policy worldwide on supply of materials and its assurance; with consequences of worldwide on supply of materials and its assurance; with consequences of the concepts of sustainable development which coupled environmental and economic consideration, industry, people, communities, and governments will realign their future perception and concepts. Environmental considerations in Namibia require that for any major development such as uranium exploration, environmental safety analysis reports are made which should incorporate community, industrial and government regulatory concerns. Namibia being a developing country, any new regulations that will consider environmental safety and regard for safe management of uranium wastes will add more pressure on present human resource needs: regulatory enhancement; and financial burden to the existing limited infrastructure. The new regulations should address the environmental effect on mill tailings which are a result of processing the uranium ore in a mill; and heap leaching residues which result from treatment of ore; tailing impoundment; tailing pile and tailing stabilization chemically or physically. From the radiation protection concepts, consideration will be made of the relationship of the new regulations and the current practice of the (ALI) recommended by the ICRP 60 of 1990 released in 1991, *vis a vis* SS-115 of IAEA for uranium intakes, considering the absence of either Nal or Germanium detector or scintillation/whole body counter in Namibia, implementation of the new regulations will require material and human resources if viable advise and training on regulatory implementation of statutory promulgation are to be enforced.

1. URANIUM EXPLORATION, MINING AND MILLING

Namibia has had several decades of uranium exploration, mining and milling. Mining is essential to the growth of our economy. The entrepreneurs are generally partners with the Government in recognizing the role of uranium mining contributes to our economic growth.

1.2. Uranium deposits

Namibia is endowed with low grade uranium resources hosted mainly in the three genetic deposit types, viz. alaskite related, surficial and sandstone type uranium deposits. The first uranium deposit, Rössing Uranium, was discovered in 1920 by a mineral prospector. Considerable number of exploration work took place from 1940 and so far 51 Uranium deposits have been found, and of these only the Rössing uranium deposit has been developed into an operational uranium mine. Others could not be developed due to low tonnage and grades found. Exploration methods include geological mapping, geochemistry of geological media, airborne radiometric surveys in many cases combined with magnetic measurements, scintillometry, percussion drilling and subsequent borehole logging. All the deposits have been compiled in a computerized database, Uranamib.

1.3. Rössing uranium mine

Rössing is a high tonnage, low grade uranium mine, located 70 km north of the coastal town of Swakomund in the Namib desert. Its host ore is alaskite. The primary mineralization (uraninite) and the majority of secondary mineralisation (beta oranophane) are economically the most important ore minerals contributing to 55% and 40% respectively of the uranium, and the remaining 5% is betafite. There are traces of uranium in brannerite, monazite, zircon sphene, apatite and fluorite.

Mine production started in 1976. The hydrometallurgical plant was commissioned in 1976, while commercial operation started in 1978. The production capacity is 3500 t U/year, which is currently reduced due to lack of long-term sales contracts. The mine complex encompasses an area of approximately 4400 hectares. Within this area is the open pit, waste dumps, ore stockpiles, milling and acid leach recovery facility, tailings impoundment and associated support facilities. The open pit is approx. 3 km long, 0.25 km deep and 1.5 km wide. It is mined in 15m deep benches.

1.3.1. Mining and milling processes

The uranium extraction process includes drilling, blasting, loading, hauling, crushing and milling. The drilling and crushing work are carried out by wet means to suppress dust. Milling and leaching processes lead to the final stage of size reduction by rodmills operating in open circuits, in two modules with two rodmills and six leach tanks each. The resulting slurry is pumped into the leaching tanks were it is mixed with sulphuric acid, ferric sulphate and magnesium dioxide. It goes through washing and thickening process, then the slime from the thickening stage and sands from the second stage rotoscoops are re-combined into immediate tailings sump and are deposited through pipelines to tailings impoundment. Yellowcake is calcinated to uranium oxide (U_3O_8 at 98.5%U) and discharged through a hammer mill to an automatic drum filling plant where it is packed in steel drums and then dispatched to overseas customer for further processing.

2. REGULATORY INFRASTRUCTURE

Environment and radiation safety is the responsibility of the Government. The Government in meeting its obligations to the regulatory set up for safe exploration mining and milling of uranium, has required that the mining companies set up and present to the regulatory authority a code of practice for the safe operation of the mining process. This code of practice is part and parcel of our regulatory requirements until we have promulgated the Atomic Energy Act under which Uranium Mining and Milling Regulations will be issued.

General Radiation Protection Regulations for the workers have been promulgated by a Presidential Proclamation under the Labour Act and are regulated by the National Radiation Protection Services Unit of the Ministry of Health and Social Services. These regulations are based on ILO Conventions and recommendations. These regulations are complemented by the National Radiation protection policy which was ratified in November 1994. The aim of this policy is to assess, control and regulate all radiation activities in the country. The Ministry of Health and Social Services is working on a broad scope licence for uranium mining operations to be issued, in the interim, under this policy.

For now, Rössing Uranium Mine is operating under a licence issued by the Ministry of Mines and Energy, under the Minerals and Prospecting Act, which is the principal statutory instrument dealing with mining activities, in general. In this regard, The Ministry of Mines and Energy is also responsible for the control of uranium exports. Later this year the Regulatory Authority will set-up a Nuclear Material Safeguard System to implement the IAEA Safeguard Agreement which was recently entered into between Namibia and the Agency.

As you are aware, Namibia has been independent for the last eight years. There are far too many laws to be amended from the colonial and racial ordinances that were in practice prior to our independence. The labour arrangement in pre-independence Namibia were geared toward ensuring that the indigenous Namibians were available at cheap costs to the mines. Condition of work in the mines for the indigenous Namibians was very bad. We have now embarked on the policy of national reconciliation. The people, industry and the government are now united towards the building of the nation.

Our current regulatory approach in the Uranium Mining Industry is to create an understanding of the protection of the worker, the environment and the general public by setting up the code of practice based on the best available practices in the world.

Rössing Uranium Mine of Namibia has developed a detailed code of practice for the protection against ionizing radiation. The primary objective of this code is to ensure that exposures of radiation will not give rise to unacceptable levels of risk and that the sources of such exposures are identified, quantified, controlled and minimized. The regulatory authority has recognized this code for operation and practices in Namibia. This code of practice was revised after the IAEA mission recommended that the operations in our mining as applied through these codes are adequate.

3. RADIATION MONITORING PROGRAMME

Under its code of practice, the Rössing uranium mine has established an extensive monitoring programme for the protection of the workers, the general public and the environment. Area and personal monitoring is carried out across the mine in all workshops, plants, equipment and in the environment. This programme forms the basis for the assessment of occupational exposures and the effectiveness of the control programme, and quantification of the mine’s environmental impact.

3.1. Background radiation

Background radiation levels are measured by exposing thermoluminescent dosimeters (TLD’s) in different areas on and off the mine site.

3.2. Personnel monitoring

The personal external radiation doses of all registered radiation workers is measured with the TLD dosimeters. All designated workers are issued with such dosimeters.

3.3. Radon, thoron and progeny

Measurements of radon working levels, radon concentrations and the radon daughter equilibrium factor are used in determining the radon dosage. The thoron dosage is derived from the relative concentration of thorium in the uranium ore. Radon concentrations are measured by track etch detectors exposed over four months to obtain a time average value. In areas exhibiting high concentrations, exposure only last for two months. Grab sample measurements are also done to supplement the track etch results. The measurement of radon exhalations with the activated charcoal detectors are conducted in all areas identified as showing an enhanced exhalation of radon.

3.4. Dust monitoring

Ambient dust level monitoring comprises the determination of the respirable and the total dust concentration. The dust concentration results combined with the sizing, uranium content and the total alpha activity are used to assess and control health and radiological hazards. Respirable dust is monitored with personal samplers in the breathing zone and in the different working areas. The high volume samplers are used to measure dust concentrations in air, and the directional samplers and fall-out plates are used to determine the dust contribution from crushers and stockpiles. Samplers of the dust collected from these monitors are sent away for radionuclide analysis which includes the determinations of gross alpha, gross beta, quantitative gamma and radium, uranium and thorium content.

Directional samplers and fall - out plates are located at the open pit, coarse ore stockpile, fine ore stockpile and the tailings dam. Samplers are placed in the four principal directions for each area. Samplers are collected monthly or when necessary and results reported annually.

4. WASTE MANAGEMENT

Radioactive wastes need to be managed both securely and safely. Security and safety entail developing and implementing relevant laws and regulations, establishing a regulatory control authority, and setting up the necessary operational capabilities. The principles of radioactive waste disposal are based on material security and maintaining their control. It is proposed that Regulatory control should include aspects that would assist customs officers, border police, other law enforcement officers, regulatory authority, and relevant bodies established in Namibia or enhance their capabilities for preventing detecting unauthorized disposal or discharge into the environment and to detect and respond to possible illicit trafficking in wastes generally.

Radioactive waste resulting from mining and milling operations, including contaminated waste materials, are disposed of and managed in accordance with approved procedures. Contaminated wastes are covered with waste rocks. Tailings from uranium extraction process is deposited through pipelines from the plant to a large valley dam impoundment. Mill tailings resulting from the leaching process of the uranium ore represent a major concern in the management of wastes from mining and milling operations. About 85% of the radioactivity originally present in the ore ends up in the tailings. In addition, the physical properties of the tailings and their chemical constituents create a potential problem of environmental contamination, which will persist for a long time after the mine has close-out. Proper tailings management, environmental monitoring and control, as well as decommissioning plans are required to preserve the current and long-term quality of the environment. Rössing uranium mine has developed a decommissioning plan which is yet to be approved by the regulatory authority.

5. PROPOSED REGULATORY INFRASTRUCTURE

The new legislation should establish a legal framework, and a regulatory authority for supporting governmental services, employers, registrants and licensees, as well as others bearing responsibility for safe mining and milling of uranium and other radioactive ores, disposal of wastes in general but paying additional attention to radioactive materials in particular.

Attention should be made of:

(a) Radioactive materials in medicine, agriculture, industry and research that are typically involved in waste generation with a view to minimization and appropriate control;
(b) The regulatory infrastructure and physical measures needed for preventing unauthorized disposal or discharges;

(c) Performance requirements, calibrations and testing of monitoring instrumentation's for the detection on compliance with disposal or discharge authorizations;
(d) Response procedure when illicit disposal or discharge is detected to remove the danger's eminence;
(e) The training requirements for persons involved in the inspection work for waste management regulatory control.

5.1. Regulatory control of discharge into environment

The regulatory Authority should be provided with sufficient powers and resources for effective regulation, and must remain independent of any government department and agencies that are responsible for the promotion, and development of the practices being regulated. It must be independent of registrant, licensees, and designers and constructors discharge practices.

For radiation protection emissions, the principles accepted for general waste safety fundamentals apply. The radiation safety fundamentals and standards in the control of discharges of radionuclides to the environment from the normal operations of practices have been recommended by IAEA Basic Safety Standards. They require that the Regulatory Authority be provided with a structured approach to limitation of risks to the members of the public and optimizing protection from such operations. This requires that guidelines be given on responsibilities of registrants and licensees in conducting discharge operations.

The scope of regulatory control of discharge into the environment should be limited to discharges into the environment of substances (including radionuclides) in the form of gases, aerosols or liquids, together with any particular materials, from the normal operations of a practice.

In addition, the law should ensure that the discharge is referred to the ongoing, or anticipated releases of harmful substances into the environment arising from normal operations of a practice or a process with a practice. Discharges of liquid substances directly to surface water bodies should be considered, but discharges of liquids substances by injection to deep underground and releases arising from accidents should be paid attention to because they pose different problems legally. They may have transboundary transportation.

5.2. Regulatory authority

The implementation of standards requires that national regulatory infrastructure be in place to enable the Government to discharge its responsibility for radiation protection and safety. An essentials part of a national infrastructure is a regulatory authority empowered to authorize and inspect regulatory activities and enforce the national legislation and regulations. The function of the authority related to discharges should include preparation of regulations, review of application to discharge materials into the environment, the approval or rejection of the applications and the granting of authorizations; the conduct of periodic inspections to verify compliance; and the enforcement against any violations of regulations, standards and license conditions. The effectiveness of safety measures for each authorized discharge together with its total potentials impact on man and the environment should be assessed.

5.3. Inspectors

The powers of the inspectors of the regulatory authority must be clearly defined and consistency of enforcement must be maintained, with provision for appeals by those responsible for discharge Wastes. Directives to both inspectors and regulated persons must be clear. Regulated persons mean: “any organization, corporation, partnership, firm, association, trust, estate, public or private institution, group or administrative entity or other persons designated in accordance with national legislation’s, who or which has responsibility and authority for any action taken under national regulatory standards”.

5.4. Legal administrative requirements

(a) Practices should not be allowed or otherwise be introduced, conducted or discontinued except in accordance with the appropriate requirements of legal standards. Any legal person intending to undertake any of these actions ‘shall submit a notification to the Regulatory Authority of such an intention”, and shall apply for an authorization in form of a license or a registration.

(b) Exclusions from regulatory control should be clearly stated. In case of radiation discharges, it includes gaseous discharges, through building ventilation systems of radon and associated daughters arising from building materials. In general, exclusion refers to any discharge exposure whose hazards are magnitude, or likelihood is essentially unamenable to control through the legal standards.

(c) Exemptions from the requirements of regulatory control standards. The authority should be able to grant exemptions in cases where it is clear that practice is justified but regulatory provisions are unnecessary or unwarranted i.e. the risks to individuals, population and the environment caused by the exempted practices are inherently low as to be of no regulatory concern and that the exempted practice is inherently safe.

(d) Standards must prescribe limits for discharges. The exemptions are therefore below the prescribed limits.

(e) Clearance levels should be stated below which no administrative control is necessary.

6. CONCLUSION

Regulatory control is an evolutionary process which can be more effective if it is based on a process of review and correction, rather than setting precise conditions prior to allowing a process to proceed which cannot be changed to respond to the many out side impacts which can affect a process over its life cycle.

In the absence of relevant regulations, Namibia has developed a National Radiation Protection Policy, the company codes of practice is revised, regulation are being prepared to bring the future regulatory process in line with the new regulatory approach; and in addition, to enable the country to respond to new challenges and meet them, and make regulatory process commensurate with the level of risk associated with exploration, mining and milling, and associated tailing management and rehabilitation. To realize these efforts, manpower situation would need to be improved, appropriate equipment provided and inspectors empowered to assess, monitor, and regulate the uranium industry.
It is hoped that this meeting will recognize the special nature of our regulatory infrastructure and the effort that the Rössing uranium is making in protecting the workers, the environment and the public.

THE LEGAL AND REGULATORY FRAMEWORK RELATIVE TO SAFETY AND ENVIRONMENT IN THE URANIUM MINES IN NIGER

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Abstract

The mining sector holds an important position in Niger economy. Considerable funds have been invested for the promotion, exploration and exploitation of mineral resources since the colonial period. This has resulted in the discovery of numerous deposits among which those of uranium. Today, uranium represents more than ¾ of Niger export revenues. The mining sector is supervised by the Ministry of Mines and Energy. The Ministry applies the mining policy as defined by the government. It elaborates legislative and regulatory texts and see to their implementation. Regarding uranium, mining activities has been governed since 1961 by various orientation laws and implementation decrees. However, to face up the harmful consequences on national economy of successive drops of price and sales of its major export product, and taking account the new internationl requirements relating to economy globalization and sustainable development, Niger set up a diversification strategy of its mining productions as part of which a new mining code particular incentive has been established in 1993. The new mining code provides significant advantages to investors. These advantages insure them a great cost effectiveness of their investments in Niger and easy and less onerous respect of regulations regarding safety and protection of environment. Tremendous efforts have been, thus, provided by the IAEA, the Ministry of Mines and Energy and the uranium companies for an optimal protection of workers and the public, especially against the hazards of ionizing radiations. This will to improve the situation has resulted in the adoption of several laws and their application decrees as well as various sectorial laws designed by various Ministry departments concerned with environmental issues and risks prevention. Among these texts are the renewal of the order N° 31 M/MH which has defined since 1979 the main axis of the Niger regulations as regards to radioprotection and the design of new texts relating to radioactive wastes management and the transportation of radioactive materials.

1. INTRODUCTION

Many people heard about NIGER in literature as a great uranium producing country (if not confused to NIGERIA).

Indeed, Niger is currently the third uranium world producing country and the first in Africa.

The discovery of first indications of uranium dated back to the 50's. The first commercial production of yellowcake dated back to1971.

This is why, uranium mining has been the first industrial activity in Niger which has benefited very soon from legislative and regulatory framework governing all aspects of its activities and especially specific risks to hazards exposure to ionizing radiations.

2. AIM OF THE PAPER

The aim of this paper is to present the modest experience of Niger as regards to uranium and other mineral substances mining regulations with emphasis on environmental issues and risks prevention and their consequences on exploration, mining, mineral processing and wastes management activities.

The plan of the paper will be as follows:

(a) A brief introduction to the physical and macro-economic framework of Niger;
(b) A brief overview on resources and types of uranium deposits in Niger;
(c) A brief overview on the institutional framework of mining activities in Niger;
(d) Regulation in uranium and other mineral resources in Niger;
(e) Regulation practice in uranium mining companies in Niger.

3. PHYSICAL FRAMEWORK

3.1. Geographical situation

Niger is located in the heart of the north-western part of the African continent, surrounded in the north by Algeria and Libya, in the east by Chad, in the west by Burkina Faso and Mali, in the south by Nigeria and Benin (Fig. 1).

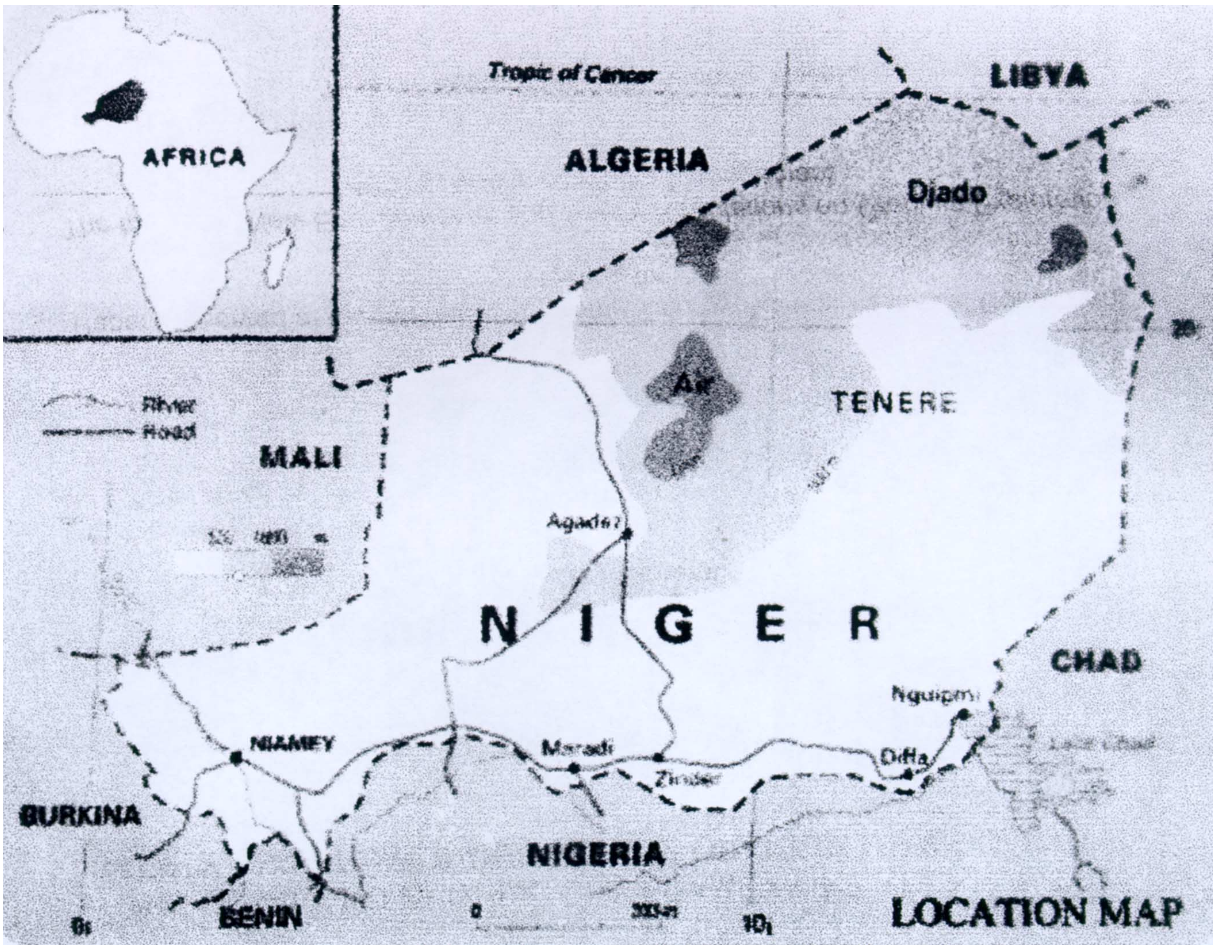

FIG. 1. Location map.

Located in full Sahelian zone, it covers 1 267 000 square kms for a population estimated to 9.5 million inhabitants in 1997. French is the the official language. The rural sector (staple food agriculture and extensive cattle rearing activity) provides jobs to 85% of the population and contribute for 40% of the GDP.

3.2. Mining and petroleum potential

From economic point of view, Niger, however, can be considered as a rather mining country, not for the volume or diversity of its mineral productions but for:

(a) The position occupied by the mining sector in the national economy;
(b) Its considerable mining potential;
(c) Its long mining tradition.

3.2.1. Role of the mining sector in national economy

During the years of « the Uranium boom in Niger » (1975-1981) uranium has contributed for 20 to 25% of GDP, 40% of the country budget revenues, 85% of the export revenues and provided an economic mean growth of 21% and employment for more than 4,000 permanent salaried employees.

Nowadays, despite the drastic drop of price and sales, uranium still represents more than 75% of Niger export revenues.

3.2.2. A large and diversified geological potential

In addition to uranium, around thirty mineral substances (gold, silver, nickel, cobalt, titanium, lithium, lanthanides, chromium, vanadium, etc. and fossile fuels (coal, oil)) and near 400 indications and deposits have, up to now, been registered though mineral investigations have only been carried on a tiny part of the national territory.

In fact, in front of the dramatic consequences on the socio-economic sector due to successive drops of price and sales of the nuclear fuel since the beginning of the 80's, and in order to avoid the dangers and fragility of an economy based upon the monoproduction of uranium, the Ministry of Mines and Energy has set up an all directions diversification policy of the national mineral productions.

Thus, intensive geological investigations for the setting up of basic geological infrastructures and several promotion actions in the international mining fora have been conducted.

This resulted in the granting of several exploration permits to international companies (majors and juniors) from Canada, UK, Norway, Germany, South Africa, Australia, etc. among which: Ashanti Goldfields, Anglo-American, Barrick Gold, Etruscan, etc. for gold and other precious metals, Exxon, Hunt Oil, Tg World Energy for hydrocarbons.

The territory of Niger is mainly located within the Central African mobile zone which slightly overlaps the western African craton at the Liptako region. Niger mining potential is mainly related to (Fig. 2):

- The Phanerozoic sedimentary formations of the immense basins of Iullumenden in the West (Iullemenden, Ader - Doutchi, Tin Mersoï and Tamesna sub - basins) and the ones of Chad to the east, covering 90% of the national territory.

  The stratigraphic series of the sedimentary basins run from the Cambrian to the Pleistocene and are characterized by alternating marine and continental sequences.

It is, in particular, in the basin of Iullemenden, characterised by an alternance of layers with a marine influence and continental complexes that have been discovered the important coal (Anou Araren, Solomi) and uranium deposits some of them in exploitation stage (Arlit).

- The formations of the Precambrian basement which outcrop in the metallogenic provinces of Liptako (30,000 km^2), Aïr (60,000 km^2), Damagaram - Mounio and South Maradi (20,000 km^2) and Tenere (13,000 km^2). These formations are essentially made of gabbros, dolerites, basalts, andesites, rhyolites, intermediary basic tuffs, granitoids, sedimentary sequences, etc. and are known for their indications in Au, Pt, Cr, Cu, Pb, Zn Ti, Li, V, etc.

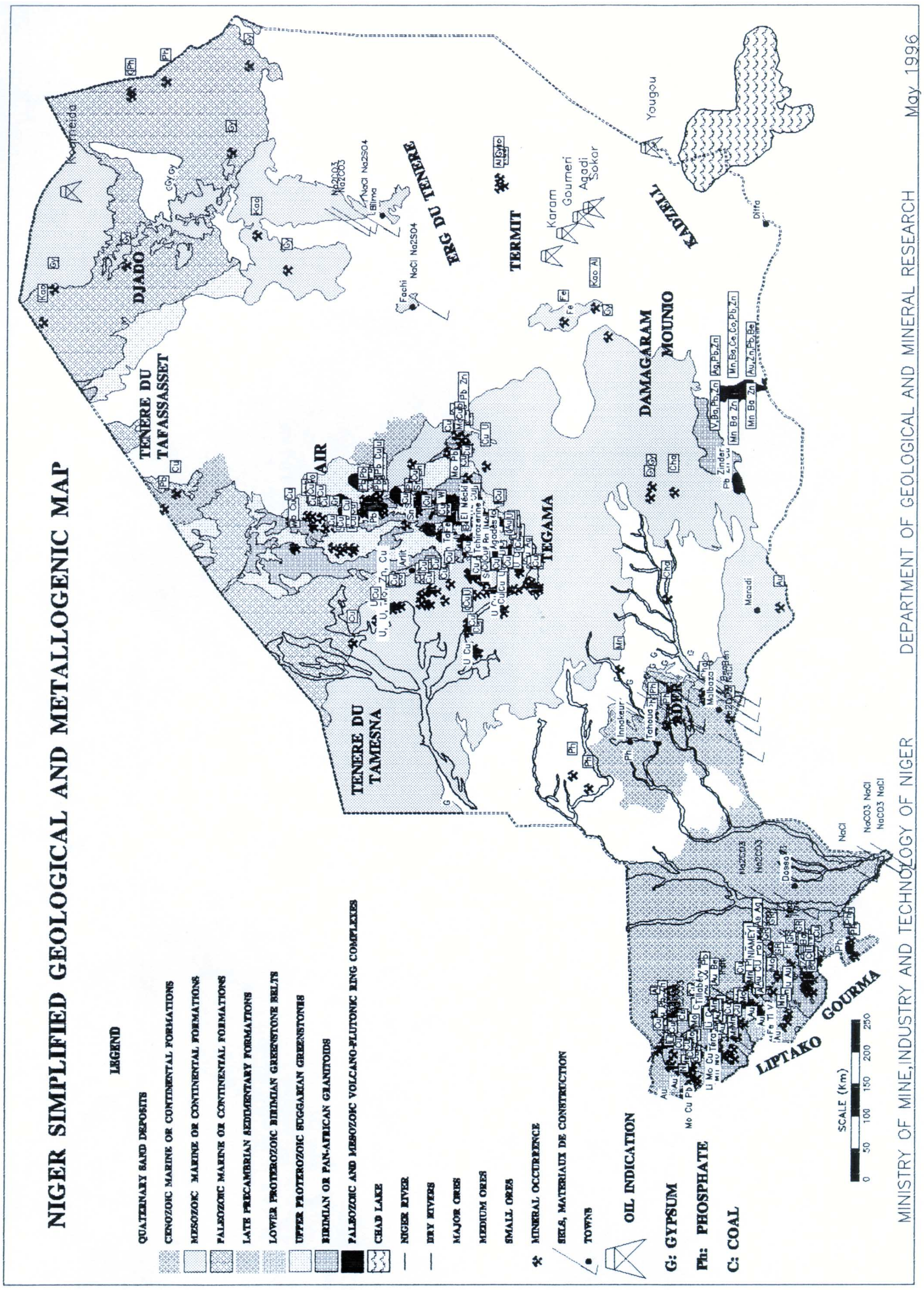

FIG. 2. Simplified geological and metallogenic map of Niger.

3.2.3. Mining industry experience in Niger

Niger has a long mining experience.

Industrial mining has begun in Niger in 1946 with tin production, followed by that of uranium in 1971, phosphates in 1975 and coal in 1981.
However, from its importance in the national economy, uranium remains undoubtedly the economic and social development engine of Niger.

4. URANIUM RESOURCES AND TYPES OF DEPOSITS IN NIGER

4.1. Location

Uranium deposits of Niger are located in the region of Arlit/Agadez in the central north-western part of Niger at an equal distance with the Mediterranean Sea and the Gulf of Guinea (Figs. 3a and 3b).
The climate is desertic, dry and the temperature exceeds 45°C during the dry season. It rains scarcely (under 100 mm/year). Sandstorms are frequent during the raining season from May to September.

4.2. Stratigraphy

Uranium deposits are around 35 m to 250 m depth in sandstone – clay sedimentary formations with a continental origin for sandstone and marine for clays.

These formations relay on the western border of the crystalline Massif of Aïr in the basin known as Tin Mersoi (Agadez Basin).

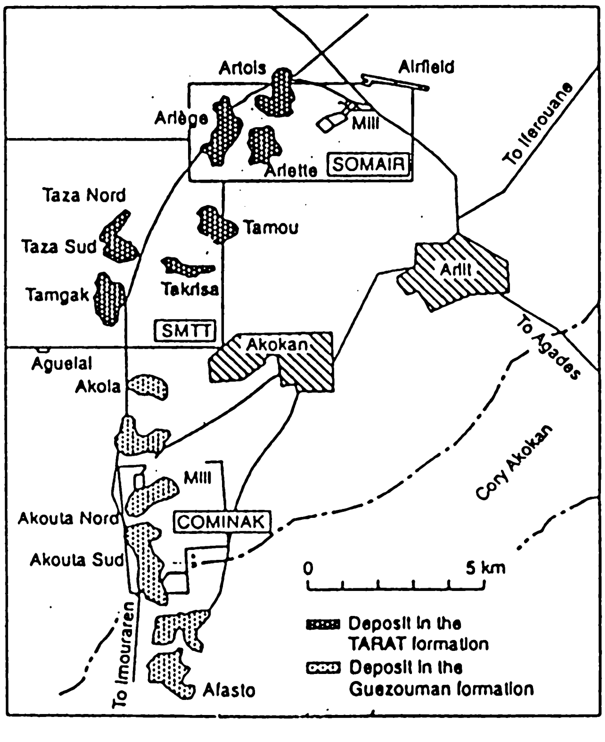

FIG. 3a. Uranium deposits and prospects in Niger.

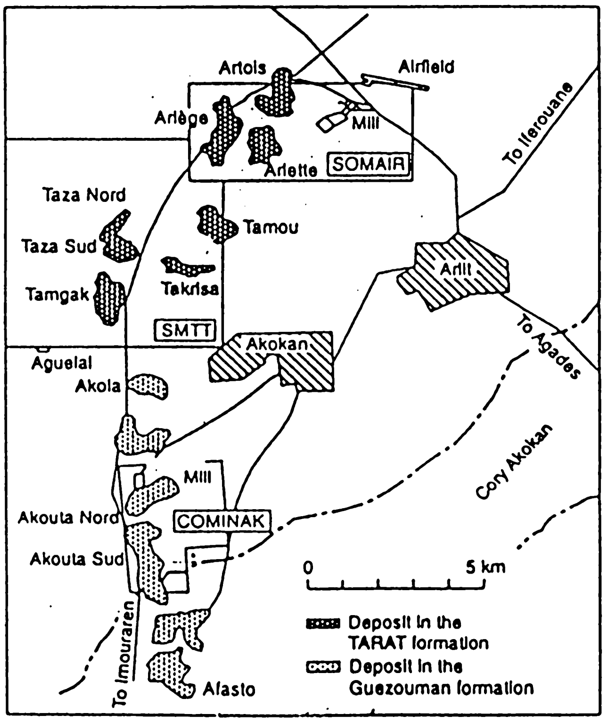

FIG. 3b. Uranium deposits in the Arlit region, uranium producing district of Niger.

In general, the whole system is sub-horizontal with local variations of dip.

Uranium mineralization is associated with upper Carboniferous units, principally in the Guezouman, Tarat and Madouela sandstones. The upper continental sequence (Irhazer) can also indicate some mineralizations (Fig. 4).

The host rocks of uranium mineralizations consist of sandstones, siltstones or argillites. Clay are, regarding to their content in organic materials, at the origin of uranium trapping. Uranium exits:

(a) In clays in split form, linked, to the phyllites,

(b) In sandstones in the form of pitchblende (oxyde) and coffinite(sillicate).

Incidentally associated are molybdenum and vanadium at low grade and also some iron sulfides.

4.3. Uranium resources and mining in Niger

The estimated uranium resources of Niger represent a total of 281,000 tons of uranium spread over a dozen of mining permits, each containing one or many deposits. The resources consist of 180.860 tU of RRA and RSE-I and 100.800 tU of RSE-II and RS.

The Takriza, Tamou, Artois, Arlette, Ariège, Afasto West, Madaouella, Akola, Akouta, Teguidan Tessoum, Abkoroum Azelik, Imouraren orebodies are among the most importants uranium deposits of Niger.

Some of these deposits are being developed or mined either by open cast method (Somaïr) or by underground method (Cominak).

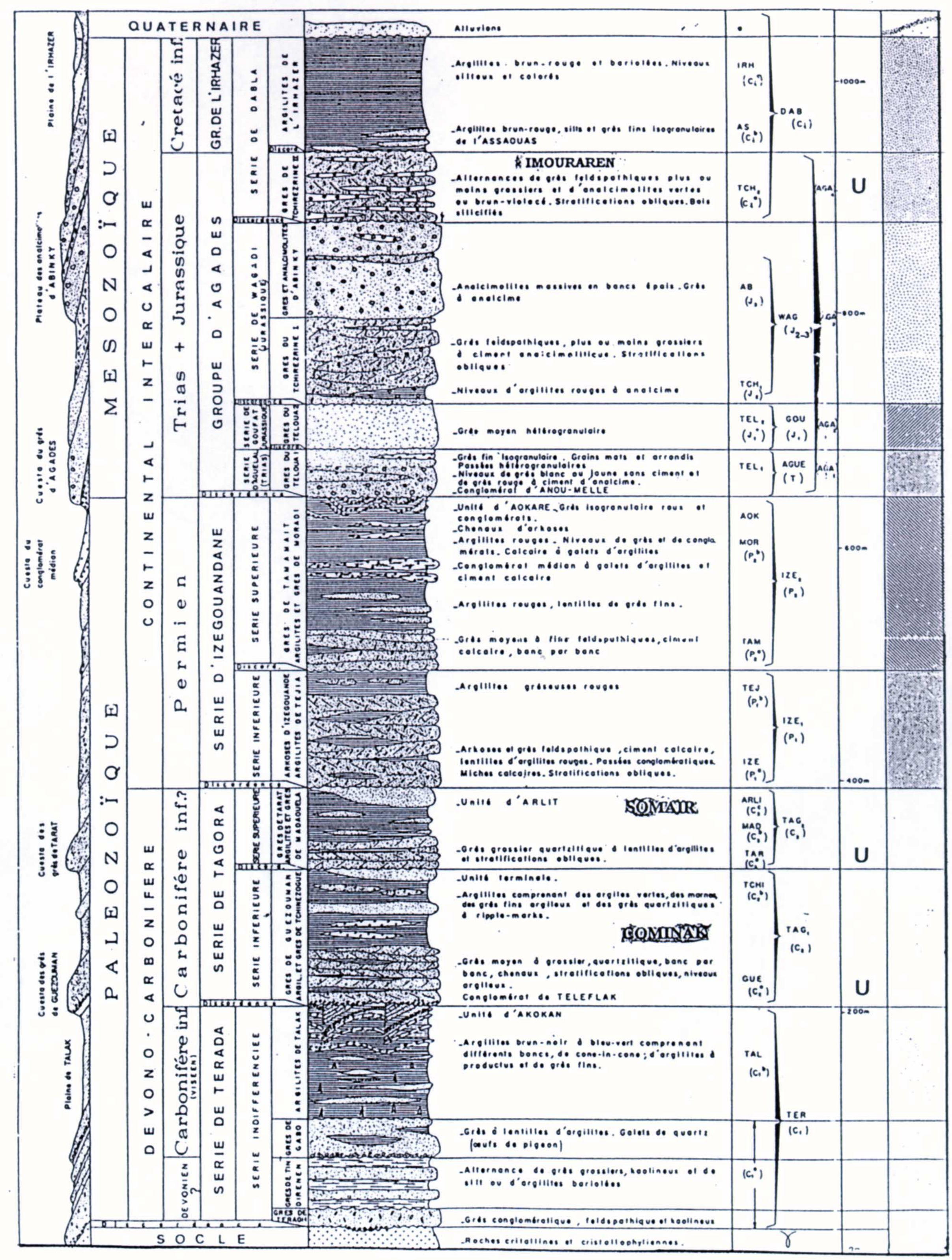

FIG. 4. Stratigraphical section of the Tin Mersoï Basin.

In both cases, the processing method is the acid leaching with extraction by solvents (Table I). The 1998 production is 3,500 tons of uranium.

TABLE I. URANIUM MINING COMPANIES CHARACTERISTICS.

Name of the Company	SOMAÏR	COMINAK
Date of Creation	1968	1974
Put in Service Date	1970	1978
First Commercial Production	1971	1978
Production Site Name	Arlit	Akouta
Shareholders (%) :		
• ONAREM	36,6%	31%
• COGEMA	63.4%	34%
• OURD	-	25%
• ENUSA	-	10%
• Others		
Ore Source:		
• Current Deposits Name	Arlette - Takriza – Tamou	Akouta – Akola
• Deposit Type	Sedimentary (Sandstone)	Sedimentary (Sandstone)
Mining:		
• Type	Open Pit	Underground
• Daily Tonnage (metric tons/day)	8.000	1.800
• Average mine recovery rate (%)	90%	90%
Milling Process		
• Type	AL/Extraction by solvents	AL/Extraction by solvents
• Daily Tonnage (metric tons/day)	1.800	1.900
• Average recovery rate (%)	95%	93%
Nominal Capacity (tU/y)	1.500	2.300
Jobs at 31/12/97	779	1255

5. THE INSTITUTIONAL FRAMEWORK OF MINING ACTIVITIES

The mining sector is administered by the Ministry of Mines and Energy.

The Ministry is in charge, in accordance with the orientation defined by the government, of the design and the execution of the national policy as regads to mineral and energetic resources. It elaborates and executes, or make carry out exploration and prospection programs through bilateral or multilateral cooperation. It elaborates legislative and regulatory texts and see to their implementation.

The institutional framework related to the legislation on environmental issues and prevention of risks in mining exploitations involves three other Ministerial departments. These are:

(a) The Ministry of Hydraulics and Environment;
(b) The Ministry of Labour and Employment;
(c) The Ministry of Public Health.

Each of these Ministries elaborates legislative and regulatory texts depending on its attributions and or its fields of competence and see to their implementation.

Three structures of support and administrative control attached to some of these Ministries have also been created. These are:

- The radioprotection laboratory created in 1980 at the mining sub-division of Arlit on mining exploitation sites in order to perform mine and mill plant installations control and proximity surveillance actions.
- The National Committee on Radioprotection and Nuclear Technics (CTNR) created by decree N° 97-252/PRN/MME of 10 July 1997. The CTNR is an advisory organ at the Ministry of Mines and Energy for any issues related to the pacific use of nuclear energy.

  The Committee is composed with representatives of all Ministries and establishments concerned by the use of nuclear techniques: Ministry of Mines and Energy, Public Health, Employment, Hydraulics and Environment, Agriculture and Rearing, Research and Higher Education, Interior and various institutes and national research laboratories.

- The National Radioprotection Center (CNRP) created by law N° 98-011 of 7 May 1998 and placed under the tutelage of the Ministry of Public Health is the national authority in charge of all radioprotection activities.

6. LEGISLATIVE FRAMEWORK AND LEGAL INSTRUMENTS

6.1. Legal instruments

As a consequence of the plurality of actors in Administration, legislative and regulatory framework is governed by many laws and their implementation decrees, especially:

- The Labour Code recently revised (1996), whose implementation is part of the attributions of the Ministry of Labour, sets the principles of professional risks prevention in general.

- The ordinance (law) N° 97-001 of 10 June 1997 relating to the institutionalisation of environmental impact assessements is the initiative of the Ministry of Hydraulics and Environment.
- In the mining field and particularly that of uranium, mining activities have been governed since 1961 by:
  ⇒ Law N° 61-8 of 29 May 1961 related to prospection, exploration, exploitation, ownership, circulation trade and transformation of mineral or fosile resources on the territory of Niger Republic (Mining Law).
- Law N° 68-02 of 26 January1968 on fiscal regime institution for exploration, mining and physical or chemical concentration of uranium and related resources firms in Niger.
- Law N° 74-22 of 6 April 1974 fixing mining rights taxes and duties.
- The implementation decrees fixing the implementation modalities of the various laws, particularly: the decree N° 61-219/MTP of 14 October 1961, the decree N° 61-157 MTP of 24 July 1961, the decree N° 61-158 MTP of 24 July 1961, the decree N° 68-022 MTPTUMU-MF of 31 January 1968 and the decree N° 74 -154 PCMS/MMH of 25 June 1974.
- However, in order to harmonise the legislation and regulation over the entire activities related to all mineral resources, these various laws and their implementation decrees have been abrogated and replaced by a new Mining Code in 1993 according to the ordinance N° 93-16 of 2 March 1993 and its implementation decree N° 93-044/PM/MMEI/A of 12 March 1993.

However, the ongoing uranium exploitation activities at the date of these texts abrogation remain governed by the former texts.

The new Mining Code was put forward also from the necessity for Niger to face the fierce competition between the various mining countries in order to attract investments in the field of geological and mining exploration which have registered a significant decrease subsequent to the persistant crisis in which the mining industry is plunged since the beginning of the 80's.

Most of theses countries competed to revise their mining codes in order to create legal and fiscal framework that will provide more incentive.

6.2. The main articulations of the new mining code

6.2.1. Structure

(a) The code which includes the mining law and its implementation decree as well as a model of the mining convention offers the advantage to compile in a unique structured and organised document all that concerns the mining sector in Niger.

(b) The code clearly sets up rights and general conditions for the acquisition, prolongation, renewal, extension, transaction (partial cession or total transfer), relinquishment, withdrawal procedures as well as the validity duration confered to each type of the mining lincence.

(c) According to the law, the signing of a mining convention is required before the granting of an exploration or an exploitation permit. The convention is valid 40 years because it covers the exploration as well as the exploitation phase in case of discovery of an economically exploitable deposit.

(d) The object of the mining convention is to specify and to guarantee to the investor the stability of the general, legal, fiscal, economic, administrative, customs and social operations conditions during the validity period of the convention.

6.2.2. The legal framework

The mining Code makes provisions for four types of mining titles:

(a) The prospecting authorization (prospecting licence) issued for sub-surface investigations is valid one year but confers to its owner a preemption right in case of an application for extention to an exploration permit.
(b) The exploration permit (exploration licence) is valid three (3) years, renewable twice for a period of three (3) years.
(c) The exploitation permit (mining licence) is valid twenty (20) years, renewable twice for a period of ten (10) years.
(d) The artisanal mining authorization: for very small scale mining is valid two (2) years, indefinetely renewable.

6.2.3. The fiscal framework

Mining Companies operating in Niger are submitted to the following main taxes and rights:

(a) Fixed Rights: for any application related to attribution, renewal, extension, prolongation or transaction (transfer, cession) of mining titles.
(b) Mining royality: at the rate of 5.5% of market value of the final product.
(c) Direct tax on profits (BIC) at the rate of 40.5% of taxable profit.
(d) Tax on movable property revenue (IRVM): at the rate of 16% of distributed dividends.

6.2.4. Advantages conceded to the investors

The mining Code grants important advantages to the investor such as fiscal and and custom exemptions and diverses facilities among which :

(a) Exemption from all custom duty and income tax during the exploration phase;
(b) Total customs exemption from duties and taxes on importation of materials, supplies, equipment and spare parts to be used for the mining operations;
(c) Exemption from rights and taxes on exportation;
(d) Exemption from rights and taxes on bank loans;
(e) Exemption from entry duties on petroleum fuels and derivates used on fixed installations;
(f) Discounting and refund of exploration expenses during the production phase as first establishment costs;
(g) Five years income tax (BIC) holiday from the start of commercial production;
(h) Carry - over of losses forward up to three years;
(i) Quick depreciation scheme;
(j) Possibility to difere depreciation when in deficit;
(k) Deduction of the mining royalty from taxable profit for the calculation of the BIC duty;
(l) Deduction for depletion allowance up to 20% of taxable profit;
(m) Free importation and exportation of products, free convertibility and free transfer abroad of funds, dividends and outcome from capital invested;

(n) The institution of a unique desk for mining investment at the Ministry of Mines and Energy for all acquisitions and movements of mining titles formalities.

The new mining Code has strongly taken into account the environmental concerns:

(a) All prospection, exploration and mining of mineral resources activities should be conducted with respect to the physical, cultural and social environment;
(b) A preliminary environment impact assessement should be realised before the grant of any exploitation permit.

7. REGULATORY FRAMEWORK AND REGULATION TOOLS

Several regulatory texts have been designed specifying the modalities and obligations imposed to operating mining companies so that mining activities be undertaken with respect to permanent protection of the environment and the public.

Amoung these, texts relating to protection against ionizing radiations constitute specific tools linked to uranium mining activities with regard to:

(a) The structure of the associated regulation and
(b) The regulation tools themselves.

7.1. Structure of the Nigerien regulation

In order that a regulation be implemented, it must be applicable. The Niger regulation structure is inspired by the ICRP recommandations and international practices. It hinges on the known classical principles that are:

- Respective responsabilities of employers and workers.
- Description of risks dealt by the regulation.
- Objectives in terms of prevention of risks (doses limitations).
- Principles of workers allocation with regard to their exposure perspectives and classification of working zones according to the level of radioactivity (mine, yellow cake area, solid wastes areas).
- Risks limitation strategy (ventilation strategy in the case of underground mines) and general hygiene of staff.
- Methods, means and procedures for:
  (a) Surveillance of physical atmosphere in working areas,
  (b) Individual dosimetric surveillance of exposed agents,
  (c) Medical surveillance: hiring and end of contract medical examinations, periodic medical examinations, etc.,
  (d) Administrative surveillance (activity reports and control of installations).

7.2. Regulation tools

- Until 1979, all radioprotection actions carried out were based on French regulation.
- From 1979 order N°31M/MH of 5/12/79 of the Ministry of Mines and Hydraulics fixing the particular rules of safety and hygiene to which are subjected the exploration and exploitation sites of radioactive resources defines the main axes of NIGER regulation on radioprotection.

- In the light of new knowledge and experiences of regulation, a draft order on protection against ionizing radiations in the mining sector has been elaborated in 1998 within the IAEA model project « Re-enforcement of Radioprotection Facility in Niger » to replace the order N° 31 M/MH. This draft order provides some modifications on dose exposure limitation and on risks accumulation calculation formula (Table II).

8. REGULATION PRACTICE IN THE MINING COMPANIES

Both mining companies inscribed radioprotection in their global security policy. Significant financial, human and organisational means are devoted to it. The implementation of regulatory stipulations in mining companies is based on two objectives:

(a) Staff protection, particularly through radiologic risks prevention actions;
(b) Environment and public protection through environment surveillance and wastes management.

8.1. Radiologic risks prevention

Radiologic risks prevention in the two mining companies is based on the two main known methods which are: the « a priori » and the « a posteriori » methods.

(a) The a posteriori method

Enables, from the dosimetric follow up of workers, to know regularly (per month, semester and year) the dosimetric situation of each radioprotected worker according to the regulation in force. Workers whose level of exposure is close to the acceptable limit are appointed to other working positions less exposed as a preventive access.

(b) The a priori method

The prevention is guaranteed by the improvement of working conditions, the endowment of workers with suitable protection equipment, the fitting out of the place and better planing of time and working methods.
For example: the limitation of exposure time in a confined working area, mostly when the ore is rich, the building of underground fixed installations (such as worksops, cafetariats etc.) in uranium poor or waste areas, the dilution of radon through adequate primary and secondary ventilation, the systematisation of airstream helmets carring, the integral water drilling, the watering of blasted ore before loading, etc.

8.2. Control of environment

The region of Arlit is a desertic and less populated area. The implantation of the mines many kilometers from of the cities and other habitations constitute itself an important measure of people and public protection. However, a rigorous control of all the radioactive pollution vectors is moreover carried out.

Thus, at various places located around the industrial zone and the towns nearby are installed stations for the measurement of gamma dose, potential alpha energy and dusts.

TABLE II. THE MAIN AXES OF RADIOPROTECTION REGULATION IN NIGER.

Type of Exposition	Units	Order N° 31 MM/H	New Order (1998)	Remarks
External Irradiation . Entire Organism	mSv	50	50	Unchanged
Internal Irradiation : Total Alpha Activity of Long Life Daughters				
. for Uranium ore dusts	Bq	3120	5400	Less Restricting
. for Yellow Cake Inhalated Dusts	Bq	6240	2700	More Restricting
Potential Alpha Energy Of Short life Radon Daughters	mJ	17	42	Less Restricting
Divider of the external exposition ration in The Cumulative Risk Calculation Formula	mJ	150	50	More Restricting

$$\text{Cumulative Risks (TET)} = \frac{E\gamma}{150\ \text{mSv}} + \frac{E\alpha}{14.4\ \text{mJm}^3.\text{h}} + \frac{\text{Ep. Min}}{70\ \text{pCi.l}} + \frac{\text{Ep. Uranate}}{140\ \text{pCi/l}} < 1 \quad \text{in 12 Subsequent months}$$

The environment control device is essentially based on the measure of atmospheric transfers and especially the regularly (monthly, semestrial, annual) control of uranium 238 and radium 226 concentration by drinking water, soil and in gardens vegetables samplings.

8.3. Waste management

There are two main considered categories of wastes: the liquid wastes and the solid wastes from the mill plant.

The liquid wastes are stored in some basins known as evaporation basins. This is a satisfactory method because the basins are waterproof so that the infiltration risk are quasi inexistent.

Effectively, these basins are made of an embankment frame covered with banco clay and sand.

The waterproofness is ensured by a PVC geomembrane set at the bottom and along the slopes of the basin and maintained at the crest of the embankment in an enchorage trench.

On some basins, as a supplementary protection, a BIDIM or SITTEX geotextile has been placed all over the surface of the clay before the installation of the geomembrane.

The mill tailings are 20% residual humidity. The evaporation of the residual water contributes to the formation of a salt dry layer on the surface of the tailings which constitutes a short time protection against wind erosion.
All the measures taken by the mining companies in order to implement the various regulatory stipulations have shown that the impact of their activities on the people living near the sites and environment, in general, respect the national and international prescribed standards.

Thus, the measure of environment control have given, so far, values well under the international standards (1/10 of the limit for workers protection).

For the long term, a detailed study is under way for a more sustainable stabilisation method of the tailings.

9. CONCLUSION

In Niger, legal and regulatory statements stipulate that all exploration and mining activities of mineral substances must be conducted with respect to the physical, sanitary, cultural and social environment.

Thus, many laws and implementation decrees have been adopted since the 60's and others are still being worked out for an optimal protection of the public especially against the risks related to the activities of the uranium mining industry.

The structure and objectives of the Nigerian regulation are in accordance with those derived from international recommendations.

The efficiency of the prevention measures and security policies set into place by the mining companies for staff, public and environmental protection shows that uranium exploration and mining activities respect easily the current and future prescriptions with values clearly below the recommended international standards.

The preventive and palliative measures, despite the colossal organisational, human, material and financial means involved have only unsignificant impact on the uranium production cost.

THE IMPACT OF NEW REGULATIONS ON REMEDIATION OF THE AREA OF ISL IN STRAZ POD RALSKEM, CZECH REPUBLIC

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Abstract

The paper gives a short description of the situation in the area of uranium production in northern Bohemia in the Czech Republic. It gives a very short overview of legislation system, list of legislation associated with mining and remediation and procedures of mining and remediation activities licensing. At the end it gives "for discussion" some approaches and interpretation in definition of the term "mine waters".

1. INTRODUCTION

The sandstone-type uranium deposits in the northern part of the Bohemian Cretaceous basin (the so called "Northbohemian Cretaceous") were discovered in the early 1960s. The most important area, with this type of deposits are situated in the lowest part of the upper Cretaceous sedimentary complex, in the so called Straz tectonic block. The main production activities of the Czechoslovak Uranium Industry Company (CSUP) were concentrated in this area in the second half of the 1960s. The Straz block deposits were considered as the most prospective sources of uranium to cover the long-term needs of the Czechoslovak nuclear programme, which was then planned at a large scale.

The development of the CSUP production activities in the area of the Straz block was very fast, unfortunately without much considerations to the future. Two uranium deep mines (DH-1, DK-1) were in operation and one uranium deep mine (DH-2) was in the stage of preparation at the end of the 1980s. About 6 sq. km ISL production complex was also present in addition to these classical deep mines.

The gradual reduction programme of the uranium production in the Northbohemian area is connected with the whole Uranium Industry contraction programme and were caused by:

- decreasing uranium market in the USSR since the end of 1980s,
- loss of the Slovak market after the splitting of Czechoslovakia,
- low uranium demand in the Czech Republic after the previous reduction of the nuclear programme,
- decreasing uranium export possibility abroad (oversupply, high production costs),
- re-evaluation of the environmental criteria to limit the environment load, which was caused by the uranium production.

The uranium production contraction programme proper begun with the liquidation of the Hamr II Mine (DH-II) in the Straz block at the end of the 1980s.

The production of the Krizany Mine stopped in 1990 and its underground liquidation was completed in 1991.

The next production complex influenced by the contraction programme is the Hamr I Mine (DH-I), which was mothballed between 1993 and 1995. After the Czech Government decree No. 244/1995 liquidation of the mine started after May 1, 1995, only backfilling is being performed and underground mine should be completely liquidated by 2001.

At present, the production area of ISL covers 6.5 sq. kilometres with about 7,000 technological wells. The diluted sulphuric acid solution was used as lixiviant. A total of 330 million cubic metres of leaching solutions were circulated in the area of ISL in the period between 1967 and 1997. Additionally, 4.3 million t of sulphuric acid, 0.3 million t of nitric acid, 0.1 million t of ammonium and 0.03 million t of hydrofluoric acid were injected underground for the uranium production. A total of 15,000 t of uranium were produced during this period.

The main problem with this production method was the spreading of the leaching solutions out of the production area. An overbalance of 190 million cubic metres between the amount of lixiviant injected than produced in the proximity of the deep mine has affected the underground water covering an area of 28 sq. km.

The development of the ISL plant stopped after the Czech Government decree in 1991 and production from it was carried out at the minimum technological level after 1992. A decision about the future of ISL will be made in accordance to the Czech Government decree No. 170/1996 after the evaluation of research and verifying work done between 1992 and 1995. The liquidation of the mine started after April 1, 1996. The first step of remediation works has been implemented since July 1, 1996, with the operation of a station to suppress the technological leaching solutions with a capacity of 2.5 million cubic metres per year. It is based on evaporation and membrane processes.

Liquidation of ISL will be a long-term and expensive. In the process, it will produce uranium in the amount of about 2,000 t between 1996 and 2005.

The approach from the legislation point of view is being changed according to the new legislation as new acts, new regulations and government decrees and their implementation, as well as the newly applied procedures based on formerly existing legislation.

2. GENERAL LEGISLATION BACKGROUND

The Czech Republic originated from the Czech part of former federal Czechoslovakia after its division in January 1, 1993. Its law system is based on continental law systems, which are based on the main source of law as written law.

The law of the highest power (the highest act) is Constitution of the Czech Republic adopted by the Parliament on December 16, 1992. The State power is ensured by three elements:

- legislative power,
- executive power,
- judicial power.

Legislative power is ensured by the Parliament, which has two chambers — the House of Representatives and the Senate. The government, president and state attorney agency have executive power. Judicial power as the third part of the state power and is independent on any other part of state power and consists of law-courts on different levels.

Legal order is created by a complex of all legal norms (rules) in the state. Not all of them have the same position and they are ordered according to their legal power:

- Constitution of the Czech Republic and Constitutional Acts,
- Acts and Act Measures,
- Government Orders, Notices of Ministries and Authorities on their level,
- Public obligatory orders and notices of local regulatory bodies.

Subordinate legal norms may not be in contradiction with norms of upper legal power.

Legal norms are abstract rules, which cannot cover all social relationships and therefore there is a need for their interpretation. The following system of legal norms interpretation is base on the principle, which body gives the interpretation:

- *legal interpretation* – according to present status, there is nobody authorized for legal interpretation of legal norms now,
- *official interpretation* – it is given by the state body for its subordinate bodies and workers, therefore it is sometimes call service obligatory interpretation. It is not general obligatory interpretation,
- *interpretation of legislation applying body (building authority, water management authority etc.)* – it is also a case obligatory interpretation focused at the concrete situation and can never be used generally,
- *Interpretation in decisions and views of Law-courts* – it is only a case obligatory and not a general obligatory interpretation, but it influences legal use a lot.

3. LEGISLATION RELATED TO MINING AND REMEDIAL ACTIVITIES OF URANIUM INDUSTRY

Legislation related to mining and remedial activities has been developed for a long period of time and it has gone through many changes. Many of the changes were associated with changes after 1989.

3.1. General legislation framework related to mining and remedial activities

The following is a list of legislation related to mining and remediation activities in uranium industry in the Czech Republic according to their legal power and date of issue:

- Act No. 20/1966 Coll. on Medical Care and Public Health
- Act No. 138/1973 Coll. on Waters (Water Act)
- Act No. 44/1988 Coll. on Protection and Use of Minerals and Raw Materials (Mining Act)
- Act No. 309/1991 Coll. on Protection of Air Environment against Polluting Agents (Act on Air Environment)

- Act No. 388/1991 Coll. on State Environmental Fund of The Czech Republic
- Act No. 17/1992 Coll. on the Environment
- Act No. 114/1992 Coll. on Protection of the Nature and Landscape
- Act No. 244/1992 Coll. on Evaluation of Impact on the Environment (EIA Process)
- Act No. 18/1997 Coll. on Peaceful Use of Nuclear Energy and Ionising Radiation (Atomic Act)
- Act No. 125/1997 Coll. on Wastes
- Notice of CBU (Czech Bureau of Mines) No. 104/1988 Coll. on Economic Use of Deposits, Announcement and Licensing of Mining Activities
- Notice of CBU (Czech Bureau of Mines) No. 22/1989 Coll. on Safety and Health Protection and Safety of Operation During Mining Activities in the Underground
- Notice of CBU (Czech Bureau of Mines) No. 26/89 Coll. on Safety and Health Protection and Safety of Operation During Mining Activities on the Surface
- Notice of CBU (Czech Bureau of Mines) No. 51/89 Coll. on Safety and Health Protection and Safety of Operation During Processing of Mineral and Raw Materials
- Notice of CBU (Czech Bureau of Mines) No. 99/1992 Coll. on Construction, Operation, Stabilisation and Liquidation of Installation For Waste Deposition in the Underground
- Notice of SUJB (State Office For Nuclear Safety) No. 184/1997 Coll. on Requirements on Radiation Protection
- Order of the Government of the Czech Republic No.171/92 Coll. which Lays Down Parameters of Admissible Level of Water Pollution

This legislation gives a general framework for mining and remedial activities in the Czech Republic. Specific conditions defining the concrete steps in remedial actions were defined in some decrees of the Czech Government.

3.2. Specific legal framework related to mining and remedial activities of uranium industry

Here follows a list of Decree of the Government of the Czech Republic related to remedial activities of uranium industry:

- UV CSSR No. 94/1989 - concept for decrease of losses in uranium mining in CSSR in 1990
- UV CSFR No. 894/1990 - revision of the concept of uranium mining production decrease in CSFR related to needs of Czech nuclear power plants and report on conditions for realisation of uranium production decrease between 1990 and 2000
- UV CR No. 533/1991 - revision of concept for decrease of uranium production related to needs of Czech nuclear power plants in 1992 and following years
- UV CR No. 366/1992 - results of evaluation of uranium chemical mining in the Ceská Lipa region, scenario for close-down and remediation of deposit
- UV CR No. 429/1993 - revision of concept of decrease of production and conservation of the Hamr 1 mine
- UV CR No. 244/1995 - realisation of decrease of the uranium ore mining and milling in the Czech Republic
- UV CR No. 170/1996 - lays down liquidation and remediation of the uranium ISL mining in Straz pod Ralskem

- UV CR No. 427/1997 - report on evaluation of the uranium ore mining and milling at the Dolni Rozinka site

3.3. State regulatory bodies and administration involved in mining and remedial activities of uranium industry

Description of the state regulatory bodies and administration related to the uranium sites decommissioning and remediation are given in the following list:

- *Ministry of Industry and Trade* - founder of s.p. DIAMO, it sets tasks upon DIAMO according to the government's decrees, licenses concepts, projects and conditions of realisation and financing
  - *Building office for Uranium Industry* - licenses and permits construction of various buildings and objects performed in the framework of decommissioning and remediation of uranium sites, situated in the frame of the Ministry of Industry and Trade
- *Czech Bureau of Mines* - supervisor for mining activities, independent, officially controlled only by the Prime Minister (responsible Vice Prime Minister)
- *State Office for Nuclear Safety* - supervisor for nuclear energy use and for protection against ionising radiation with its regional offices, independent, officially controlled only by the Prime Minister (responsible Vice Prime Minister)
- *Ministry of Finance* - looking after and modifying the budget approved by the government to the Ministry of Industry and Trade for remediation works
- *Ministry of Environment* - supervisor, administration in the field of the environment with its regional offices
  - *Czech Inspection of Environment* - supervisor in all parts of the environment (air, water, protection of the landscape and forest, waste), requires remediation of negatively influenced areas, implements penalties and sanctions, controlled by Ministry of Environment
  - *Local Offices of Environment* (in the framework of regional and local authorities) - makes final decisions on licensing activities having influence on the environment, methodologically under Regional offices of the Ministry of Environment (groundwater, air) or Ministry of Agriculture (surface water, forests, agricultural land)
- *Ministry of Health* - supervisor in all aspects of possible health influence
  - *Office for Expertise and Managing of Emergency Situations* (former Office for Working Environment Hygiene) - supervisor for hygiene and safety of work, controlled by Ministry of Health

3.4. Remediation project licensing

The system of remediation project preparation, submitting, approval and licensing in the Czech Republic is not so simple as it seems to be. The essential basis for any remedial project is a government decree where the Government sets requests and tasks. DIAMO is the only organisation, which is involved in remediation of the uranium mining and milling sites and is controlled by Ministry of Industry and Trade. The Ministry authorises all projects and its financing.

Financial sources are allocated each year from the state according to the specific documentation called “Actualisation of the Uranium Industry Contraction Programme” which is prepared out annually by DIAMO and submitted to the Ministry for its authorisation. After the approval in the state budget the Ministry of Finance observes its use. This way the remediation programme is checked twice.

In fact, preparation of any remediation programme could be described as follows:

I analysis and report on the current status in the uranium industry or at the given site, carried out by DIAMO and subsequently via Ministry of Industry and Trade submitted to the Government to make appropriate decision;
II the Government issues the decree giving tasks related to the remediation of the site to DIAMO via Ministry of Industry and Trade;
III DIAMO prepared a detailed schedule according to the tasks given by the government’s decree and Ministry specifications;
IV risk analysis for the site is carried out by an independent company, contracted by DIAMO, or by DIAMO itself;
V the Technical Plan of Decommissioning (TPofD) is prepared by DIAMO, and submitted to opponents for evaluation, and then to the Ministry of Industry and Trade for authorisation, the TPofD includes also a social programme;
VI technical design and plans and other documentation are prepared;
VII Environment Impact Assessment (EIA) is prepared for every single construction or technology, which is planned to be realised in the framework of remediation of the site, in accordance with the Act No. 244/1992 Coll., prevailingly by an independent company;
VIII supervision is performed by many authorities such as local offices for the environment (under the control of Ministry of Environment), Czech Bureau of Mines and its regional offices etc. during all the phases of remediation project implementation.

The annual financing is ensured in following way:

I. the Government decided all costs related to remediation of the uranium mining and milling sites will be paid from the state budget;
II. in the state budget some amount is allocated for that purposes each year;
III. the financing is authorised on the basis of “Actualisation of the Uranium Industry Contraction Programme”, prepared by DIAMO and approved by the Ministry of Industry and Trade and Ministry of Finance.

4. NEW LEGISLATION AND NEW APPROACH TO EXISTING LEGISLATION AFTER 1989

There have been many changes in the legal system after 1989. This has dealt mainly with changes in ownership and setting new conditions for development of market economy. Therefore the law can be divided into two parts:

– *new legislation* reflecting new conditions and requests of the society and external influence,
– *old legislation* more or less modified to newly originated conditions.

4.1. New legislation after 1989

There have been many parts of legislation which originated on the request of the completely new conditions in the state and of course in the world:

Act No. 309/1991 Coll. on Protection of Air Environment against Polluting Agents (Act on Air Environment)

Act No. 388/1991 Coll. on State Environmental Fund of The Czech Republic

Act No. 17/1992 Coll. on the Environment

Act No. 114/1992 Coll. on Protection of the Nature and Landscape

Act No. 244/1992 Coll. on Evaluation of Impact on the Environment (EIA Process)
This Act deals with assessment of the impact of prepared constructions, their changes and changes in their use, activities, technologies and development concepts and programmes and products on the environment and sets the authorities of the state administration pertaining to environmental impact assessment.

Act No. 18/1997 Coll. on Peaceful Use of Nuclear Energy and Ionising Radiation (Atomic Act)
This act newly covers all the former subordinate legislation and deals with ways of nuclear energy use and ionising radiation and conditions for performance of the associated activities, system of protection of individuals and the environment against the undesirable influence of ionising radiation. It sets duties for intervention to decrease the influence of natural and accidental radiation, special requests to ensure responsibility for damages caused by radiation accidents. It sets conditions for safe radioactive wastes deposition, execution of the state administration and supervision during the use of nuclear energy and during activities leading to irradiation and over nuclear items.

Act No. 125/1997 Coll. on Wastes

Order of the Government of the Czech Republic No.171/92 Coll. which Lays Down Parameters of Admissible Level of Water Pollution.

4.2. New approach after 1989 to legislation existing before 1989

Act No. 138/1973 Coll. on Waters (Water Act)
Surface waters and groundwaters are one of the raw sources, which are an important part of natural environment and serve for covering of economic and other social needs.

There are three types of water defined in article 2 of the Act:

- surface waters,
- groundwaters,
- special waters — other legislation (Mining Act).

Act No. 44/1988 Coll. on Protection and Use of Minerals and Raw Materials (Mining Act)

This act sets the rules for protection and economic use of raw materials especially during prospection, exploration and exploitation of raw materials deposits, processing associated with their exploitation, safety of operations and environmental protection.

5. CASE EXAMPLE ON "MINE WATERS"

5.1. Definition of terms for "Mine Waters"

As mentioned above, definition of the term "mine waters" is excluded from the Water Act and should be properly defined in the Mining Act. Article 40 of the Act defines "mine waters" as:

... all groundwaters, surface waters and precipitation waters, which penetrated underground or surface mine spaces ...

The term "mine spaces" has not been properly defined in any legislation. It is only mentioned in decision of the Czech Bureau of Mines No. 1820/1989 article 4, paragraph 3 using following words:

... creation of new mine spaces - e.g. by tunnelling or mining.

The term is also mentioned in the norm ON 44 6305 and in the article 242 of the Notice of the Czech Bureau of Mines No. 22/1989.

This is not a "Platonic" discussion, because the Water Act defines payment duty when groundwaters and surface waters are used, the Mining Act sets no payment duty on "mine waters" when used for operational needs. This could spent a big amount of money from the operators budget, because of not properly defined term in legislation.

5.2. Some questions and interpretations of "Mine Waters" in case of In Situ Leaching (ISL)

What are mine spaces?

Are the spaces only in the ISL production and monitoring wells (defined as mine workings) or the space in the productive horizon, where ore is present, or the space in all horizons from the surface, where ISL was licensed?

Are waters in well "mine waters" and surrounding waters are groundwaters? Then we can pump without any limitations, because waters are pumped from the well as "mine waters" although they were groundwaters shortly before pumping started.

How can "mine spaces" be defined horizontally or vertically for ISL?

There could be discussions on this topic for a long period of time. But this case example shows, how complicated and mainly expensive can be the actions when the right definitions and descriptions are not used in the corresponding legislation.

6. CONCLUSIONS

The above mentioned problems are only a part of the problems which grew out not only because of the new legislation, but mainly because of the new approach taken by the administrative agencies for the legislation, which has been in force for a longer period of time. There are some examples in the interpretation of law, where lawyers and the administrative approach to the problem are in higher influence than the approach to reach practical solutions and the use of sanity.

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PRESENT STATUS IN THE FIELD OF MANAGEMENT OF TAILINGS FROM URANIUM MINING AND MILLING ACTIVITIES IN THE CZECH REPUBLIC

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Abstract

New criteria accepted in the Czech Republic are described. Many of them are following internationally endorsed standards published in ICRP 60 and BSS. The main attention is devoted a license procedure, a discharges of radionuclides into the environment, limits of irradiation, technical aspects for ensuring radiation protection, monitoring programme, close out of mines and mills and radioactive waste management.

1. INTRODUCTION

The need for changes in the Czech legislation was raised using new internationally endorsed standards in nuclear safety and radiation protection. The result of these changes is new the Czech Act on Peaceful Utilization of Nuclear Energy and Ionizing Radiation (Atomic Law). Basic requirements on ensuring radiation protection given by the Atomic Law are defined more detailed in the Czech regulation on the need to ensure for radiation protection. Does the practical application of these requirements and rules brink some problems?

2. DETAILS FOR ENSURING THE SAFETY OF URANIUM MINES AND MILLS MANAGEMENT

2.1. General conditions for ensuring radiation protection

(I) Licensee has a duty to fulfill the following provision:

(a) Whoever is utilizing nuclear energy or performing radiation practices or interventions to reduce natural exposure or exposure due to radiation accidents must maintain a level of nuclear safety, radiation protection, physical protection and emergency preparedness such that the risk to the life and human health and to the environment shall be kept as low as reasonably achievable, economic and social factors being taken into account. Implementing regulation shall establish the technical and organizational requirements and guidance levels of exposure, which are considered to be sufficient to demonstrate a reasonably achievable level, or an alternative procedure to demonstrate this level.

(b) Licensee must ask for permission for the:

- decommissioning of a nuclear installation or a workplace with significant or very significant ionizing radiation source (uranium mining and milling tailings);
- discharge of radionuclides into the environment; materials, substances or objects may be used outside the work site with ionizing radiation sources, they may be discharged in water or into the atmosphere, they may be stored at dumps or otherwise discharged into the environment without any license under the fulfilling defined conditions (clearance levels);
- ionizing radiation sources management in the extent and in the manner established in an implementing regulation;

– radioactive waste management;

and must submit to regulatory authority the following documentation.

Documentation for the issue of a license for individual stages of decommissioning of a nuclear installation or workplace with significant or very significant ionizing radiation source.

(1) Evidence of availability of finance for decommissioning activities.
(2) Description of changes to local area due to nuclear installation operation.
(3) Description of technical procedures proposed for decommissioning.
(4) Decommissioning time schedule.
(5) Method of dismantling, decontamination, conditioning, transport, storage and elimination of parts of installation contaminated by radionuclides.
(6) Assumed types and activities of radionuclides discharged into the environment and radioactive waste generated.
(7) Method of radioactive waste management, including its disposal.
(8) Limits and conditions for safe management of radioactive waste during decommissioning process.
(9) Safety analyses.
(10) Scope and method of measurement and evaluation of exposure of exposed workers and other persons and contamination of the workplace and its vicinity by radionuclides and ionizing radiation.
(11) On-site emergency plan.
(12) Evidence of provision of physical protection of decommissioned nuclear installation.

Documentation specified under items 8, 10 and 11 shall be subject to approval by the Office.

Documentation for the issue of a license to discharge radionuclides into the environment.

(1) Justification of discharge of radionuclides into the environment.
(2) Types and activities of radionuclides discharged into the environment.
(3) Evaluation of exposure of critical group of the population from discharged radionuclides.
(4) Analysis of a possible accumulation of radionuclides in the environment in the case of long-term discharging.

Documentation for the issue of a license for ionizing radiation source management.

(1) Justification of the radiation practices.
(2) Specification of used radiation sources, their types and accessories.
(3) Description of workplace and its surroundings (schematic plan of the workplace) supplemented by information on shielding and protective facilities and equipment of workplaces.
(4) Evidence of optimization of radiation protection at workplace under Article 4, par. 4 of this Act.
(5) Delineation of controlled area, anticipated number of personnel working in this area and method of preventing entry of unauthorized persons into this area.
(6) Operating instructions for safe handling of ionizing radiation source.
(7) On-site emergency plan.

(8) Scope and method of measurement (monitoring programme) and evaluation of exposure of exposed workers and other persons and contamination of workplace and its vicinity by radionuclides and ionizing radiation.
(9) Assumed types and amount of radionuclides released into the environment and assumed type and amount of radioactive waste generated, and method of disposal of this waste.
(10) Document on the special professional competence of personnel directly manage the working activities with ionizing radiation sources and perform other activities especially important from the radiation protection viewpoint, as laid down in implementing regulation.
(11) Type specification of ionizing radiation sources that are to be manufactured.
(12) Evidence of capability to measure and verify properties of ionizing radiation sources which are to be manufactured, and their conformity with a given type.
(13) Type specification of ionizing radiation sources that are to be imported.
(14) Document demonstrating provision for measurement and verification of properties of ionizing radiation sources that are to be imported and their conformity with a given type.
(15) Type specification of ionizing radiation sources that are to be exported.
(16) For exportation of ionizing radiation sources defined in implementing regulation, additionally a document acknowledged by a competent body in the country of the consignee proving that the consignee fulfils all conditions for ionizing radiation sources management.

Documentation specified under items 5, 7 and 8 shall be subject to approval by the Office.

Documentation for the issue of a license for radioactive waste management.

(1) Description of equipment and technology used.
(2) Information on origin, type, amount, radionuclide structure and activity of radioactive waste.
(3) Method of collection, sorting, storage, processing, conditioning and disposal of radioactive waste.
(4) Assumed amount of radionuclides released into the environment.
(5) Scope and method of measurement (monitoring programme) and evaluation of exposure of exposed workers and other persons and contamination of workplace and its vicinity by radionuclides and ionizing radiation.
(6) Safety analyses.
(7) On-site emergency plan.
(8) Document on the special professional competence of personnel directly manage the working activities with ionizing radiation sources and perform other activities especially important from the radiation protection viewpoint.
(9) Limits and conditions for safe management of radioactive waste.

Documentation specified under items 5, 7 and 9 shall be subject to approval by the Office.

(II) For other persons working in an environment where there is an increased risk of natural irradiation, which applies especially to such cases as, e.g. work in spas, water works, caves, mines, or underground areas, where, even after the implementation of corrective measures, it is impossible, during the performance of work, to reduce the volume activity of radon in the atmosphere to less than 1000 Bq/m^3, the reasonably achievable level of radiation protection is when requirements are applied which refer to work in a controlled area of work sites with ionizing radiation sources.

2.2. Irradiation limits

(I) The radiation limits as binding quantitative indicators, which must not be exceeded from the point of view of radiation protection.

(a) The basic limits for workers with sources are:
- the sum of effective doses from external irradiation and the load of effective doses from internal irradiation, has the value of 100 mSv for a period of five successive calendar years,
- the sum of effective doses from external irradiation and the load of effective doses from internal irradiation, has the value of 50 mSv per calendar year,
- an equivalent dose in an eye lens has the value of 150 mSv per calendar year,
- an average equivalent dose in 1 cm^2 of skin has the value of 500 mSv per calendar year,
- an equivalent dose to arms from fingers to forearms and for legs from feet to ankles has the value of 500 mSv per calendar year.

(b) Derived limits referring to the same irradiation cases as the basic limits for workers do, but expressed in quantities that are easier to measure than the basic limits are used for an evaluation of workers in uranium industry.

When the set derived limits are not exceeded, it is considered a fulfillment of the requirement not to exceed the basic limits for workers with sources. If there are other means of irradiation (e.g. external irradiation, internal irradiation as a result of swallowing radio-nuclides, internal irradiation as a result if inhaling radio-nuclides), observance and maintenance of the basic limits for workers with sources is considered a fulfillment, if the sum of the quotients of irradiation from a single method of irradiation and of the relevant derived limits is less than one.

Derived limits for internal irradiation

(a) a personal dose equivalent in the depth of 0.07 mm has the dose of 500 mSv per calendar year,
(b) a personal dose equivalent in the depth of 10 mm has the value of 20 mSv per calendar year,

(II) The derived limits for internal irradiation, apart from the cases set out in paragraphs 4 and 5, are:

(a) for radio-nuclide intake by swallowing, the values of the quotient of 20 mSv and the conversion factor h_{ing} for the radio-nuclide intake by the swallowing by a worker with sources, are as stated in Table I,
(b) for radio-nuclide intake by inhalation, the values of a quotient of 20 mSv and the conversion factor h_{ing} for the radio-nuclide intake by inhalation by a worker with sources, are as stated in Table I.

(III) Providing there is a simultaneous external and internal irradiation in the course of one calendar year, then, apart from the cases stated in paragraphs 4 and 5, the basic limits for workers are not considered exceeded, if:

TABLE I. COMPOUNDS, LUNG ABSORPTION TYPES AND VALUES OF GUT TRANSFER FACTOR f_1 USED TO CALCULATE COMMITTED EFFECTIVE DOSE PER UNIT INTAKE VIA INHALATION FOR WORKERS

Element	Absorption type(s)	Gut transfer factor f_1	Compounds
Beryllium	M	0.005	All unspecified compounds
	S	0.005	Oxides, halides and nitrates
Fluorine	F	1.000	Determined by combining cation
	M	1.000	Determined by combining cation
	S	1.000	Determined by combining cation
Sodium	F	1.000	All compounds
Magnesium	F	0.500	All unspecified compounds
	M	0.500	Oxides, hydroxides, carbides, halides and nitrates
Aluminium	F	0.010	All unspecified compounds
	M	0.010	Oxides, hydroxides, carbides, halides, nitrates and metallic aluminium
Silicon	F	0.010	All unspecified compounds
	M	0.010	Oxides, hydroxides, carbides and nitrates
	S	0.010	Aluminosilicate glass aerosol
Phosphorus	F	0.800	All unspecified compounds
	M	0.800	Some phosphates: determined by combining cation
Sulphur	F	0.800	Sulphides and sulphates: determined by combining cation
	M	0.800	Elemental sulphur. Sulphides and sulphates: determined by combining cation
Chlorine	F	1.000	Determined by combining cation
	M	1.000	Determined by combining cation
Potassium	F	1.000	All compounds
Calcium	M	0.300	All compounds
Scandium	S	$1.0\ 10^{-4}$	All compounds
Titanium	F	0.010	All unspecified compounds
	M	0.010	Oxides, hydroxides, carbides, halides and nitrates
	S	0.010	Strontium titanate ($SrTiO_3$)
Vanadium	F	0.010	All unspecified compounds
	M	0.010	Oxides, hydroxides, carbides and halides
Chromium	F	0.100	All unspecified compounds
	M	0.100	Halides and nitrates
	S	0.100	Oxides and hydroxides

Note: Types F, M and S denote fast, moderate and slow absorption from the lung, respectively.

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Element	Absorption type(s)	Gut transfer factor f_1	Compounds
Manganese	F M	0.100 0.100	All unspecified compounds Oxides, hydroxides, halides and nitrates
Iron	F M	0.100 0.100	All unspecified compounds Oxides, hydroxides and halides
Cobalt	M S	0.100 0.050	All unspecified compounds Oxides, hydroxides, halides and nitrates
Nickel	F M	0.050 0.050	All unspecified compounds Oxides, hydroxides and carbides
Copper	F M S	0.500 0.500 0.500	All unspecified inorganic compounds Sulphides, halides and nitrates Oxides and hydroxides
Zinc	S	0.500	All compounds
Gallium	F M	0.001 0.001	All unspecified compounds Oxides, hydroxides, carbides, halides and nitrates
Germanium	F M	1.000 1.000	All unspecified compounds Oxides, sulphides and halides
Arsenic	M	0.500	All compounds
Selenium	F M	0.800 0.800	All unspecified inorganic compounds Elemental selenium, oxides, hydroxides and carbides
Bromine	F M	1.000 1.000	Determined by combining cation Determined by combining cation
Rubidium	F	1.000	All compounds
Strontium	F S	0.300 0.010	All unspecified compounds Strontium titanate ($SrTiO_3$)
Yttrium	M S	$1.0\ 10^{-4}$ $1.0\ 10^{-4}$	All unspecified compounds Oxides and hydroxides
Zirconium	F M S	0.002 0.002 0.002	All unspecified compounds Oxides, hydroxides, halides and nitrates Zirconium carbide
Niobium	M S	0.010 0.010	All unspecified compounds Oxides and hydroxides
Molybdenum	F S	0.800 0.050	All unspecified compounds Molybdenum sulphide, oxides and hydroxides
Technetium	F M	0.800 0.800	All unspecified compounds Oxides, hydroxides, halides and nitrates

Note: Types F, M and S denote fast, moderate and slow absorption from the lung, respectively.

Element	Absorption type(s)	Gut transfer factor f_1	Compounds
Ruthenium	F M S	0.050 0.050 0.050	All unspecified compounds Halides Oxides and hydroxides
Rhodium	F M S	0.050 0.050 0.050	All unspecified compounds Halides Oxides and hydroxides
Palladium	F M S	0.005 0.005 0.005	All unspecified compounds Nitrates and halides Oxides and hydroxides
Silver	F M S	0.050 0.050 0.050	All unspecified compounds and metallic silver Nitrates and sulphides Oxides, hydroxides and carbides
Cadmium	F M S	0.050 0.050 0.050	All unspecified compounds Sulphides, halides and nitrates Oxides and hydroxides
Indium	F M	0.020 0.020	All unspecified compounds Oxides, hydroxides, halides and nitrates
Tin	F M	0.020 0.020	All unspecified compounds Stannic phosphate, sulphides, oxides, hydroxides, halides and nitrates
Antimony	F M	0.100 0.010	All unspecified compounds Oxides, hydroxides, halides, sulphides, sulphates and nitrates
Tellurium	F M	0.300 0.300	All unspecified compounds Oxides, hydroxides and nitrates
Iodine	F	1.000	All compounds
Caesium	F	1.000	All compounds
Barium	F	0.100	All compounds
Lanthanum	F M	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Oxides and hydroxides
Cerium	M S	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Oxides, hydroxides and fluorides
Praseodymium	M S	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Oxides, hydroxides, carbides and fluorides
Neodymium	M S	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Oxides, hydroxides, carbides and fluorides
Promethium	M S	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Oxides, hydroxides, carbides and fluorides

Note: Types F, M and S denote fast, moderate and slow absorption from the lung, respectively.

Element	Absorption type(s)	Gut transfer factor f_1	Compounds
Samarium	M	$5.0\ 10^{-4}$	All compounds
Europium	M	$5.0\ 10^{-4}$	All compounds
Gadolinium	F M	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Oxides, hydroxides and fluorides
Terbium	M	$5.0\ 10^{-4}$	All compounds
Dysprosium	M	$5.0\ 10^{-4}$	All compounds
Holmium	M	$5.0\ 10^{-4}$	All unspecified compounds
Erbium	M	$5.0\ 10^{-4}$	All compounds
Thulium	M	$5.0\ 10^{-4}$	All compounds
Ytterbium	M S	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Oxides, hydroxides and fluorides
Lutetium	M S	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Oxides, hydroxides and fluorides
Hafnium	F M	0.002 0.002	All unspecified compounds Oxides, hydroxides, halides, carbides and nitrates
Tantalum	M S	0.001 0.001	All unspecified compounds Elemental tantalum, oxides, hydroxides, halides, carbides, nitrates and nitrides
Tungsten	F	0.300	All compounds
Rhenium	F M	0.800 0.800	All unspecified compounds Oxides, hydroxides, halides and nitrates
Osmium	F M S	0.010 0.010 0.010	All unspecified compounds Halides and nitrates Oxides and hydroxides
Iridium	F M S	0.010 0.010 0.010	All unspecified compounds Metallic iridium, halides and nitrates Oxides and hydroxides
Platinum	F	0.010	All compounds
Gold	F M S	0.100 0.100 0.100	All unspecified compounds Halides and nitrates Oxides and hydroxides
Mercury	F M	0.020 0.020	Sulphates Oxides, hydroxides, halides, nitrates and sulphides
Mercury	F	0.400	All organic compounds
Thallium	F	1.000	All compounds

Note: Types F, M and S denote fast, moderate and slow absorption from the lung, respectively.

Element	Absorption type(s)	Gut transfer factor f_1	Compounds
Lead	F	0.200	All compounds
Bismuth	F M	0.050 0.050	Bismuth nitrate All unspecified compounds
Polonium	F M	0.100 0.100	All unspecified compounds Oxides, hydroxides and nitrates
Astatine	F M	1.000 1.000	Determined by combining cation Determined by combining cation
Francium	F	1.000	All compounds
Radium	M	0.200	All compounds
Actinium	F M S	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Halides and nitrates Oxides and hydroxides
Thorium	M S	$5.0\ 10^{-4}$ $2.0\ 10^{-4}$	All unspecified compounds Oxides and hydroxides
Protactinium	M S	$5.0\ 10^{-4}$ $5.0\ 10^{-4}$	All unspecified compounds Oxides and hydroxides
Uranium	F M S	0.020 0.020 0.002	Most hexavalent compounds, e.g., UF_6 , UO_2F_2 and $UO_2(NO_3)_2$ Less soluble compounds, e.g., UO_3, UF_4, UCl_4 and most other hexavalent compounds Highly insoluble compounds, e.g., UO_2 and U_3O_8
Neptunium	M	$5.0\ 10^{-4}$	All compounds
Plutonium	M S	$5.0\ 10^{-4}$ $1.0\ 10^{-5}$	All unspecified compounds Insoluble oxides
Americium	M	$5.0\ 10^{-4}$	All compounds
Curium	M	$5.0\ 10^{-4}$	All compounds
Berkelium	M	$5.0\ 10^{-4}$	All compounds
Californium	M	$5.0\ 10^{-4}$	All compounds
Einsteinium	M	$5.0\ 10^{-4}$	All compounds
Fermium	M	$5.0\ 10^{-4}$	All compounds
Mendelevium	M	$5.0\ 10^{-4}$	All compounds

Note: Types F, M and S denote fast, moderate and slow absorption from the lung, respectively.

H_p (0.07) ≤ 500 mSv and at the same time

$H_p (10) + \Sigma h_{j,inh} I_{j,inh} + \Sigma h_{j,ing} I_{j,ing} \leq 20$ mSv

where:

H_p (0.07), or H_p (10) is a yearly personal dose equivalent in the depth 0.07 mm, or 10 mm,
$I_{j,inh}$, or $I_{j,ing}$ is a yearly intake of j^{-th} radio-nuclide by inhalation or swallowing,
$h_{j,inh}$, or $h_{j,ing}$ is a conversion factor of j^{-th} radio-nuclide by inhalation or swallowing by the worker with sources (see Table I).

(IV) For irradiation by radon reduction products, the derived limit is 3 MBq for a yearly intake of equivalent radon activity (which corresponds to the intake of latent energy of radon transformation products 17mJ) or 2.5 MBq.h.m^{-3} for exposure to radon products or 1260 Bq.m^{-3} for the yearly average equivalent of volume radon activity.

(V) For irradiation by a compound of long-term radio-nuclides emitting alpha radiation of uranium-transformation series, the derived limit is from intake by inhalation 1850 Bq per calendar year.

2.3. Organizational and technical measures for ensuring of radiation protection in uranium industry

A controlled zone is demarcated in all areas, where it is expected that during common operations or during predictable deviations from common operations, irradiation could exceed three tenths of the basic limit for workers. If manipulation with sources of ionizing radiation is not otherwise substantiated by special means, e.g. time limited usage, it is necessary to demarcate a controlled zone in areas where the following is expected:

(a) input of an effective dose per workplace from external irradiation will be higher than 2.5 μSv/h,
(b) the sum of the product of volume activities of individual radio-nuclides in the workplace atmosphere and conversion factors h_{inh}, for intake by inhalation by a worker, according to table I, will be greater than 25 μSv.m^{-3},
(c) surface contamination of the workplace will be greater than 30 kBq.m^{-2}.

If it is not possible to fulfill all requirements for demarcation of controlled zone which are given in other provision of the regulation, controlled zone is not determined. Such work place must be monitored the same way as controlled zone.

2.4. Monitoring programme requirements

The monitoring programme comprises, according to the method of handling of ionizing radiation sources or radioactive wastes, by rule, the following:
(a) workplace monitoring,
(b) personnel monitoring,
(c) monitoring the outlet,
(d) monitoring the surroundings.

The monitoring programme must include, for common operation as well as for predictable deviations from common operation and radioactive incidents and even radioactive accidents, the following:

(a) demarcation of variables to be monitored, methods, extent and frequency of measurements,
(b) manuals for the evaluation of measurement results,
(c) reference values and an overview of precautions in case of their overrun,
(d) specifications of measuring methods,
(e) specifications of parameters for the types of measuring apparatus and accessories that are used.

The monitoring programme must be proposed in such a way and to such an extent that during the operation of a workplace it will enable the verification of radiation limiting requirements; proving that radiation protection is optimized and securing other requirements for safe operation of a workplace with ionizing radiation sources, namely the timely location of deviations from common operation. Monitoring is, according to the nature of the matter, proposed either as systematic (routine), non-stop (continuous), or as regular (periodic) when, in stipulated intervals, it is repeated or is operational during a certain activity with an goal of evaluating and securing the acceptability of this activity from the system limitation standpoint. If changes are made in the arrangement of the workplace, sources of ionizing radiation, methods, and conditions of their handling or in the monitoring method, then the monitoring programme is updated.

Special requirements are addressed to particular part of monitoring programme.

3. CONCLUSIONS

Implementation of basic recommendations from ICRP 60 and BSS to Czech legislative was done as a first step to an improvement of level radiation protection in the Czech Republic. However, the first experiences show us that for better understanding of all the requirements which are given by the Act on Peaceful Utilization of Nuclear Energy and Ionizing Radiation and regulation on the requirements for ensuring of radiation protection, it would be practical to prepare a specific guide for the uranium industry.

IMPACTS OF NEW ENVIRONMENTAL AND SAFETY REGULATIONS ON URANIUM MINING, MILLING AND WASTE MANAGEMENT IN CHINA

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Abstract

Nuclear power progress has triggered the development and innovation of nuclear fuel industries in China. At present the Chinese government has put more emphasis on industrial readjustment and technical innovation in uranium mining and milling in order to fuel the nuclear power development, satisfy environmental protection and improve economic efficiency of the industry. The current organizations and approval procedure for establishing regulations and the implementation and consequences of the regulations, technical polices and development strategies concerning uranium mining, milling, treatment of waste ores and mill tailings, and reduction of the workers' suffered exposure dose etc. in China are discussed and the economic, health and environmental impacts of the uranium mining and metallurgy with reformation achievement and the introduction of advanced technologies such as the in-situ leaching and heap leaching mining technologies are assessed in this paper.

1. INTRODUCTION

China has devoted to the establishment and development of a complete nuclear fuel cycle (NFC) system, including uranium resource exploration, uranium mining and processing, uranium conversion, fuel manufacture, reactors irradiated fuel reprocessing and REU recycle for over 40 years. Since 1979, China's nuclear industry has changed its emphasis to serve the national economy and people's live, especially nuclear power. Consequently, the working emphasis of China's nuclear fuel cycle industry is also transferred to this aim.

The passed two years were regarded as the crucial years of start-up to the development for China's nuclear power programme. The construction of 4 nuclear power projects with 8 units in total planned for the Ninth Five-Year Plan period, i.e. from 1996 to 2000, has been in full swing. A new nuclear industry system with nuclear power as the leading effort has come into being [1, 2, 7, 8].

Nuclear power progress has triggered the development and innovation of nuclear fuel industries in China. At present the Chinese government has put more emphasis on technical innovation in uranium mining and milling in order to satisfy environmental protection and improve economic efficiency of the industry.

The current organizations and approval procedure for establishing regulations and the implementation and consequences of the regulations, technical polices and development strategies concerning uranium mining, milling, treatment of waste ores and mill tailings, and reduction of the workers' suffered exposure dose etc. in China are discussed and the social-economic, health and environmental impacts of the uranium mining and metallurgy with reformation achievement and the introduction of advanced technologies such as in-situ leaching and heap leaching mining technologies at the turn of the century are assessed in the following.

2. BASIC POLICES CONCERNING THE DEVELOPMENT OF MINING AND MILLING INDUSTRY

Since the middle of 1980s, with the consideration of the domestic condition and reality of nuclear fuel industry, following basic polices have been applied to the development of uranium mining and milling industry in China [1, 8, 9, 12]:

– Principle of peaceful use of nuclear technology for nuclear power programme to set up brand-new modernized and economical uranium mining and milling industrial system to match with nuclear power development;
– Establishment of the progressively new type operation mechanism and group enterprises and joint-stock corporation with every effort to follow the management system of modern enterprises in order to keep abreast with the development of national market economy;
– Combination of open-up and domestic orientation of fuel supply and promotion of international co-operation between China and foreign countries in developing the nuclear power and fuel market in China. Stressing on technical R & D, and meanwhile, introducing, digesting and absorbing foreign advanced techniques aims to improve the equipment and technical level of local mining and milling industry;
– Abiding by the state and international regulations on radiation protection and environmental protection to ensure the safety of uranium mining and milling facilities and personal.

3. PRINCIPLES FOR REGULATION DRAFTING

Uranium exploration, mining, milling and waste management, because of the radioactivity, will cause radioactive exposure dose to mining and milling workers and long-term threat or hazards to public health, safety, and environment if not properly managed. Hence, the industry of uranium mining and milling relates not only to complicated activities in technical and economic fields, but also to social-political issues which are concerned by and sensitive to the general public and various social communities.

In order to ensure the safe management of uranium mining, milling, treatment of waste ores and mill tailings, etc., besides the general principles, the following basic principles have been formulated and followed in drafting the relevant regulations [15].

4. SAFETY FIRST

The basic safety objective of uranium exploration, mining, milling and waste management lies in the appropriate and optimum methodology to be used in uranium mining and milling industry, so that unacceptable hazards to human health and the environment can be avoided at present as well as in the future; the design and operation of any facilities and system or any activities in respect of uranium mining, milling, treatment of waste ores and mill tailings must meet the requirements for radiation and environmental protection, and principles for protecting future generations.

5. ECONOMY

This principle is subject to the following conditions:

(a) The feasibility in technique and economy must be considered when the specific objectives and requirements of each process in uranium exploration, mining, milling and waste management are determined;
(b) For the regulation and standardization of a specific process in uranium exploration, mining, milling and waste management, both its economic rationality and the comprehensive economic rationality in the whole uranium mining and milling industry shall be considered. Although there are some difficulties in this cost-benefit analysis, in any case, it is important to define this principle; and
(c) Taking into account the technical and social factors, the ALARA principle has to be implemented to keep the individual and the collective dose lower than the specific limits.

Adopting international and foreign state-of-the-arts regulations according to national conditions

It is a common principle to be followed in various projects of uranium exploration, mining, milling and waste management. Firstly, it is easily accepted by the circles of the sociality if the international and foreign general principles and limits on safety & environmental protection in this field are incorporated into Chinese regulations and standards. Secondly, the implementation of this principle will facilitate the international co-operation.

Organization and approval procedure

The current organizations and approval procedure for establishing the regulations and standards of uranium exploration, mining, milling and waste management in China are shown in Figure 1, which is consistent with the uranium mining and milling industry system approved by the authorities concerned.

CNNC - China National Nuclear Corporation

The CNNC directly under the State Council is a national extra-large industrial conglomerate and undertakes the tasks of production, management, scientific research, development and construction in nuclear industry, including:

(a) the exploration, assessment, exploitation and extraction of nation wide radioactive mineral resources;
(b) empowered by the State, examination, registration and licensing of qualification certificates for radioactive geology survey and exploitation;
(c) designated by the State, authorizing and issuing professional regulations and standard in uranium exploration, mining, milling and waste management. etc.

GBGE, CNNC - The General Bureau of Geological Exploration of CNNC

The GBGE, CNNC is in charge of prospecting and exploration of uranium resources. It has established bureaux of geologic exploration in east, central-south, northwest, south, northeast and southwest of China and the Beijing Research Institute of Uranium Geology.

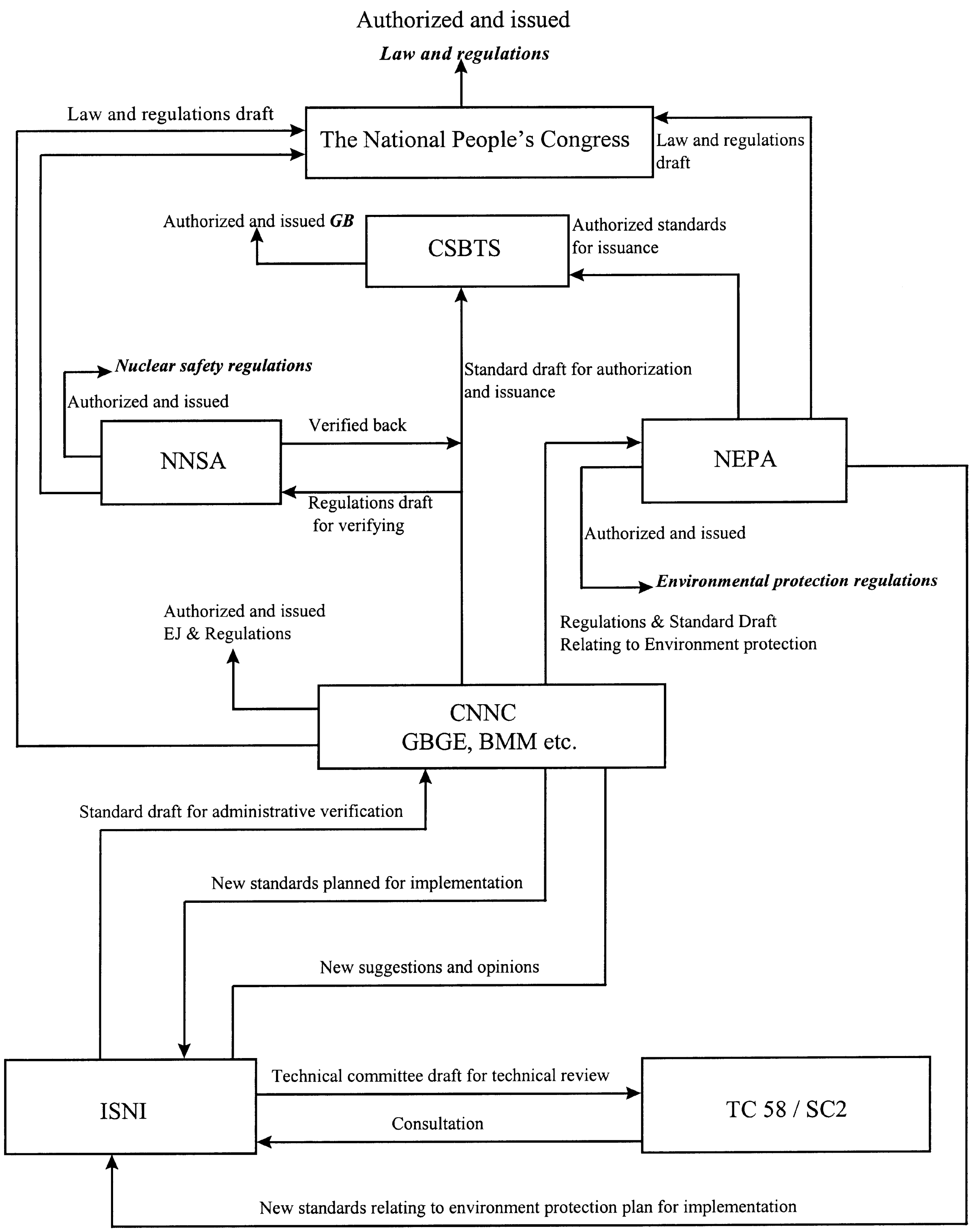

FIG. 1. Procedure for establishing the regulations and standards of uranium exploration, mining, milling and waste management in China.

BMM, CNNC - The Bureau of Mining and Metallurgy of CNNC

The BMM, CNNC possesses dozens of enterprises and institutions, covering uranium mines, ore radiometric sorting plants, mills and some institutes. It has been engaged in exploitation and production of uranium compounds, such as ADU, AUC, UO_2, U_3O_8 etc.
NNSA - National Nuclear Safety Administration

The NNSA, as a functional institution under the State Council, is responsible for managing the national nuclear safety and performs unified management and supervision of the nation wide safety issue in peaceful uses of nuclear energy and nuclear techniques, and enacts the principles, policies and regulations applied to nuclear safety.

NEPA - National Environmental Protection Agency
CSBTS - China State Bureau of Technical Supervision
ISNI - Institute for Standardization of Nuclear Industry
TC 58/SC 2 - The National Technical Committee for Standardization of Nuclear Energy/Subcommittee for Radiation Protection
EJ - Nuclear Professional Standard of the People's Republic of China
GB - National Standard of the People's Republic of China
CSTIND - the Commission of Science, Technology and Industry for National Defence

Status of the regulations

A comparatively integrated and applicable system associated with regulations/standards on uranium exploration, mining, milling and waste management has begun to take shape. It embodies the experience in uranium mining & milling industry over the past 30 years in China, and reflects the generally accepted international regulations and advanced experience on uranium mining, milling, treatment of waste ores and mill tailings, etc.

Some typical environmental and safety regulations regarding uranium mining, milling and waste management are as follows:

(1) Environmental Protection Law of the People's Republic of China (promulgated by Order No.22 of the President of the People's Republic of China, 1989)
(2) Regulations for radioactive protection (GB 8703-88)
(3) Regulations for the safe management of wastes from the mining and milling of uranium and thorium ores (GB14585-93)
(4) Normalized limits of radioactive effluent discharges for nuclear fuel cycle facilities (GB 13695-92)
(5) Regulations for design of tailing storage of uranium mining (EJ725-93)
(6) Inspection and surveillance for safe operation of tailing storage of uranium mining (EJ794-93)
(7) Technical rules for safe management of waste from the mining and milling of uranium and thorium ores (EJ/T 683-92)
(8) Regulations for environmental management of decommissioning of uranium mining facilities (GB14586-93)

Now the competent authorities are paying much more attention to industrial structure regulation, advanced movement mechanism and technical innovation in uranium mining and milling in order to fuel the nuclear power development, satisfy environmental protection and improve economic efficiency of the industry.

6. IMPACTS OF THE REGULATIONS

Uranium mining and milling industry in China, through readjustment and reform over the past ten years, has experienced great changes, considerable progress achieved. Up to now, historical readjustment tasks have been fulfilled, the main achievements are as follows:

6.1. Keeping the rational level of the production

The uranium production as readjusted shall serve primarily the needs of nuclear power development, and the policy of "self-reliance of natural uranium" shall be implemented. Uranium production capacity has been kept at a rational level to meet the requirement of nuclear fuel in recent nuclear power development. The quality criteria of uranium products can be applied also in the production of nuclear power-grade uranium dioxide, resulting from readjusting the whole process through research and development, as compared to those exclusively supporting military purposes; and professional standards have been formulated.

Following the export of natural uranium from China, two national standards, i.e. Uranium Concentrates and Ammonium Uranyl Tricarbonate were issued in 1988 so as to comply with the request in forms and quality standards of uranium products during normal trade activities in world uranium market.

6.2. New enterprises, new movement mechanism

Several mines and mills were closed down or stopped production because of resources exhausted and less social-economical efficiency while three new joint enterprises of uranium mining and milling were put into operation around 1990s, i.e. Yining Mine (Xinjiang), Lantian Mine (Shannxi) and Benxi (Liaoning). Thus, appropriate production level can be kept for uranium industry to meet the growth of uranium demand by the end of this century, and also distribution of production optimized to improve the quality of the uranium mining and milling enterprises as a whole.

Yining Mine is the first enterprise in China specialized in in-situ leaching process, the production amounting to 100 t U in 1996. In China, Lantian Mine is the first to use surface heap-leaching process and underground-blasting in-situ heap-leaching process in uranium mining. Benxi Mine, which was put into production in 1996, uses full-hydraulic rock bench drill and carry-scraper in mining, and it is the first to use the strong acid-curing and ferric-trickle heap-leaching process in commercial production. The latest findings of research and development in mining and milling technologies developed in recent years in China are used in these three plants.

At the same time, a series of administrative reform measures, such as adopting new personal engagement regime, new project contract system and regulations about non-operating assets stripped to local government or community etc., are implemented in construction and management of the mines, technical and economic indexes greatly raised as compared with those in other old mines and mills.

Though the production capacity of each mine and mill enterprise is not so large, their experience plays an important role as a demonstration engineering in construction of new uranium mining and milling enterprises as well as renewal and reconstruction of the existing mines and mills in the future.

6.3. Renewal and reconstruction of the conventional mines and mills

Renewal and reconstruction have been carried out extensively in the conventional uranium mines and mills proceeding with production so as to speed up their technical progress and improve their social-economic efficiency.

During the reconstruction of milling plants in Hengyang Uranium Mill, Fuzhou Uranium Mine and Renhua Uranium Mine, technology and equipment newly-developed in China have been adopted, linking-up in integrated milling process as a whole improved, planning of intermediate products changed, work flow simplified, and consistency with mining capacity in mines strengthened, which have made the aims met in energy-saving, material consumption reduction and economic-benefit improvement. The key equipment and facilities which have been put into production after successful research and development include 5421-type radiometric sorter, high-efficient thickener, horizontal belt filter, low-layer fluidized-bed scrubbing column, full counter-current multi-layer mixer-settler, fluidized-bed precipitator, etc.

Breakthrough progress in testing and production relating to uranium mining by using in-situ leaching process have been achieved successively in Yunnan and Xinjiang Provinces. Soon after large-scale commercial application of heap-leaching technology succeeded in Ganzhou Mine (Jiangxi), this process in deferent modes, as tested and disseminated now in many other mines, have been employed satisfactorily in production. At the same time, a complete heap-leaching process suitable to local mines has been found out. Now, uranium products produced by using in-situ leaching and heap-leaching processes account for about 60% of the annual production.

While adjusting uranium production capacity and raising production efficiency, the staff members and workers associated with uranium production have been appraised and reduced in number, and non-uranium products and industries developed by laid-off persons using surplus facilities. The personnel working in uranium production was reduced to 8,500 in 1996 compared to 45,000 in 1984. The all-personnel average labor productivity of uranium mines and mills is six times of that in early 1980s. In uranium industry, 26,000 persons were shifted to other trades, and another 10,000 persons moved to other departments over the past 10 years.

As a matter of fact, developing non-uranium production and stripping non-operating assets to local community in the conventional mines and mills also ensures the steady adjustment of uranium production, lightens the burden of uranium-oriented enterprises. Meanwhile, price of products can be competitive in world market through deepening reform, strengthening management, strictly business accounting, raising labor productivity, and reducing cost constantly.

6.4. Developing the uranium extraction and purification techniques applicable to China

There are four principal types of uranium deposits in the known uranium resources in China. Those that are in volcanic rock (20%), in granite (36%), in sandstone (21%) and in carbonaceous-siliceous-pelitic rock (15%) [11, 13]. In view of different types of uranium ores existing in China, processes have been adopted in production to develop uranium extraction and purification techniques suitable to China [6, 13, 16].

6.4.1. Treatment of volcanic-rock uranium ore by using synergistic Eluex process

The synergistic Eluex process was used to recover uranium from dilute ore-sludge adsorption by D2EHPA+TRPO (dialkylphosphorus extractants + neutral phosphorus extractants) instead of TFA. The application of D2EHPA+TRPO synergistic extractant effectively restrains Mo and iron being extracted, the product purity thus ensured. In addition, the uranium loading capacity of the organic phase of synergistic Eluex system is higher than that of the trifatty amine system, the extraction efficiency hence raised. This process is particularly applicable to China and with wide suitability is advantageous both in treating low-grade ore to ensure high purity of product, and in making full use of reflux to reduce the discharge volume of waste water, which gains good economic returns and social benefits.

6.4.2. Treatment of granite-type uranium ore by using clarification extraction process

The granite-type uranium ore is characterized by high grade of uranium, fast sedimentation of ore sands, severe resin wearing, unsuitable for ore-sludge adsorption extraction process. The successful development of highly-efficient polyacrylamide (PAA) flocculant and highly-selective tertiary amine extractant creates a favourable condition for industrial application of clarification extraction process. Prevention of emulsification during extraction is an important prerequisite for realizing the clarification extraction process. Industrial production shows that treatment of uranium ore of this type by using the clarification extraction process is the best way to gain satisfactory technical and economical indexes, and the total uranium recovery ratio can be over 93%.

6.4.3. Treatment of carbonaceous-siliceous-pelitic uranium ore with alkaline extraction process

The hydro-thermal altered carbonaceous-siliceous-pelitic uranium ore bearing high carbonate constituent can hardly be treated with acid process. A process has been successfully developed, which can directly extract and recover uranium from alkaline leaching solution by using quaternary ammonium, instead of direct precipitation process with NaOH or alkali ion exchange process, and this technology has already been applied in commercial production. In the meantime, recycling of alkaline solution creates favourable conditions to improve the utilization ratio of alkali. Through alkali thickening and reverting, the remaining solution after extraction partially returns for countercurrent scrubbing operation with the alkali reverting ratio of 72%, so that the production cost can be reduced considerably. Good technical and social-economical indexes have been achieved during production through correctly solving the problems, step by step, such as organic phase poisoning in organic and sulphide extraction by using quaternary ammonium, and quaternary ammonium loss controlled within the range of 40-50 mg/l. The process features simplicity, stable operation and high-quality products.

6.4.4. Development of in-situ leaching technology to treat sedimentary sandstone uranium ore

In sedimentary sandstone uranium deposit, the cause of formation, associated mineral elements in uranium lodging state and country rock characteristics are very complicated. Sandstone, clay rock, limestone and organogenic rock are the primary constituents in sedimentary rock. The country rock is closely related to the geo-chemical behaviour of uranium mineral formation, and different types of the country rocks are different in oxidation - reduction characteristics. The in-situ leaching technology has been applied in commercial mining of friable sandstone uranium deposit in Xinjiang. The study is being speeded up, which covers in-situ leaching technology of mineral deposits under different geological conditions, in-situ leaching area control, and underground water restoration [3, 4, 14].

According to recent statistics, over 10% of uranium resources are suitable for utilization of in-situ leaching technology. It is a common understanding that the principal advantage of in-situ leaching mining over conventional mining are financial, there are several others such as less energy intensive, low labor intensity per unit of product and less surface disturbance and pollution etc. Therefore, great effort is being made in developing in-situ leaching technology to realize the target that the production of uranium mining by using in-situ leaching accounts for over 30% of total uranium output in China in the near future.

6.5. Emphasizing the environmental protection and restoration technologies development

During the development of uranium extraction and purification techniques, effort is also being made on the study of environmental protection and restoration technologies such as volume reducing and modifying of neutralized sludge from acid waste treatment of uranium ore heap leaching [18], technologies for treating the pollution of the waste ores and mill tailings and installations decommissioning of uranium mining and metallurgy [17, 19], and technologies involving uranium extraction from uranium-bearing lignite, i.e. uranium extraction and recovery using ore sludge in large orifice-plate pulse column from acid-leaching ore sludge with uranium-bearing coal ashes etc.

6.6. Forwarding to an environmentally acceptable and harmless industry

According to the administrative laws and regulations, efficient ways must be adopted to treat the waste ores and mill tailings with radioactive elements produced during the production of uranium mining and metallurgy. Further improvement on hygienic and environmental protection would facilitate uranium mining and milling operations to be transformed into an environmentally acceptable and harmless industry. The following steps are being taken in the industry [3, 5, 10, 19]: discharge volume of radioactive effluents from uranium mines and mills should be strictly brought under control, and relevant control and management programme drawn out on the basis of optimized analysis; in uranium mining and milling, environmental monitoring system should be improved, and monitoring scheme and QC system be optimized; more effective measures should be taken to reduce the occupational exposure to workers in mines and mills, and surrounding local residents. It is stressed that transportation of radioactive materials and storage of solid radioactive waste follow the relevant laws and regulations.

The mining and milling industry in China is progressing to an environmentally acceptable and harmless industry.

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IMPACT OF NEW ENVIRONMENTAL AND SAFETY REGULATIONS IN ARGENTINA

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Abstract

Mining and processing of uranium ore has been carried out since the early fifties at several locations in Argentina. For the purpose of this presentation only the Malargüe Complex will be discussed. The second facility that will be discussed is the Cordoba Complex where uranium oxide is being produced. Since 1986, the Malargüe Complex is no longer in operation and is in the process of being decommissioned and rehabilitated. Both facilities are owned and operated by the Government's Comisión Nacional de Energia Atómica (CNEA). Two Government agencies are responsible for the implementation of the newly established Nuclear Law (Ley Nuclear), the Comisión Nacional de Energia Atómica and the Autoridad Regulatoria Nuclear (ARN). The new law follows well established international standards for radiological safety. Furthermore, any mining operation in Argentina is also governed by the country's established Mining Code. Under these regulations any new proposals will have to submit environmental impact assessments and the required public hearings before it can be approved. Thus avoiding past mistakes where practically no precautions were taken during the planning or operation stages.

1. INTRODUCTION

Uranium ore deposits have been mined in the Republic of Argentina since the early fifties, and yellow cake has been produced using different metallurgical processes in several sites.

At the end of the production stage, the facilities were decommissioned by the operator, according with the procedures approved by the Regulatory Authority and the tailings were confined and monitored to avoid their dispersion into the environment, but without final disposal.

The present regulations and standards, internationally accepted, propose a suitable management of the tailings with the objective to return the disturbed ecosystem to the community either in the same or similar conditions from the originals.

It was realized that it was necessary to adapt other experiences to our domestic scenario. Hence, it was essential to apply an interdisciplinary analysis methodology which would allow to understand the relationship between the environmental systems and the radiological and non radiological pollutants distribution.

2. PRESENT CONDITIONS IN ARGENTINA

2.1. Uranium deposits

At present, the main known deposits, with economically exploitable reserves, are:

Sierra Pintada (Mendoza Province)

It is located 1200 km to the west of the city of Buenos Aires in the foothill of the mountain chain of Los Andes. The updated uranium resources amount to a total of 5900 t U in the category “Reasonably Assured Resources” (RAR) < $130/kg U and 2400 t U in the category RAR < $80/kg U.

In the category “Estimated Additional Resources (EAR)-I a total of 910 t < $80/kg U. This deposit, is currently in stand-by and is one that supplies our uranium production plant.

Cerro Solo (Chubut Province)

It is located 1600 km to the southwest of the city of Buenos Aires, at 630 m above the sea level and in a plateau that allows to work all year round.

This project is, at present, in the stage of advanced intensive exploration, more than 500 holes have been drilled in a 300 hectares area.

The main ore bodies are 70 to 110 m deep, 3 m of average thickness and grading between 0.3 to 0.5% of uranium. The mineralization is of tabular type and of irregular distribution with frequent high grade and thickness concentration. This project is exploring the viability of integrating a Join Venture agreement to carry out the trial feasibility study of the deposit with an option to start operation by the investor. During the period 1995 and 1996, a total of 12,000 m of evaluation drilling was carried out. This has produced a recent update of the reserves to a total of 2,330 t U under the RAR < $80/kg U category and an addition of 2,830 t U in the category EAR-1 < $130/t U.

Our country has sufficient uranium to supply our reactors. But as a consequence of the opening of our economy, the evolution in the international market and our internal costs, at present, we are buying uranium, under the form of concentrate, from the international market, and only a small amount comes from of our production plant.

2.2. Uranium mine and mill tailings

In the country there are several sites with uranium mine and mill tailings. They are still under the control of the operator waiting for the final disposal. Among these are the Malargüe and Córdoba complexes.

Malargüe Complex

The Malargüe facility of the Comisión Nacional de Energía Atómica (CNEA) is located about 500 m NE of the northern outskirts of the town of Malargüe. The town is 420 km south of the city of Mendoza, the capital of the province.

About 700,000 metric tons of uranium tailings were disposed off during 32 years of operation of the Malargüe mill. The average grade of uranium ore processed by the mill was 0.14% uranium.

The SW edge of the tailings disposal area is about 100 m from the administrative offices of the Malargüe mill. The tailings, which were deposited between 1954 and 1986 on an eight ha pile, can be classified as dry to semidry.

Since 1986 the facility is no longer in operation but its responsibility is still assumed by the operator (CNEA).

Córdoba Complex

The Córdoba Complex is situated in the city of Córdoba, the capital of the province, in the down town area. There, uranium dioxide production facility is currently in operation. At this site 18,000 metric tons of uranium mill tailings were disposed off until 1978. At that time other activities were also developed in the complex.

3. LEGISLATIVE AND REGULATORY FRAMEWORK

3.1. Ley nuclear (nuclear law)

The Nuclear Law establishes the responsibilities in the nuclear field. Two organisms are included: the "Comisión Nacional de Energía Atómica" - CNEA (National Atomic Energy Commission) and the "Autoridad Regulatoria Nuclear" - ARN (Nuclear Regulatory Authority).

The CNEA is the promoting organization of the nuclear activities and it has the responsibility of the radioactive waste management. In respect to uranium mining, it can develop all and related activities as private companies.

The ARN establishes the regulations and requirements and is the enforcement organism.

3.2. Norma Básica de Seguridad Radiológica AR 10.1.1 (Basic Standard of Radiological Safety) 1995

The purpose of this standard is to achieve an appropriate level of protection for people against the risks associated with the exposure to ionizing radiation and the radiological safety of the facilities or the practices.

The scope of the standard is limited to the protection of human beings only. It is considered that standards of protection that are adequate for this purpose will also ensure that no other species is threatened as a population, even if individuals of the species may be harmed.

The standard has requirements for practices and interventions.

The competent authority in this matter is the "Autoridad Regulatoria Nuclear" (Nuclear Regulatory Authority) ARN. It is a prescriptive regulatory authority.

3.2.1. Requirements for uranium mine and mill tailings

In the framework of the AR 10.1.1 standard are the RQ-86 and the RQ-85 requirements for the uranium tailings management of the Malargüe and Córdoba Complexes.

They establish that:

(a) the critical group should not receive a dose higher than 0.1 mSv per year, and
(b) a long term waste management should be done.

Actually the 0.1 mSv/year dose is in a revision process.

3.3. Código de Minería (mining code)

The Mining Code (MC) determinates that the mining must be done in accordance with policy, safety and preservation rules of the environment. It establishes the environmental protection legislation frame.

The environmental and mining agencies in each provinces are the enforcement authorities of the code.

The scope of this code covers:

(a) all mining activities, such as prospection, exploration, development, etc.
(b) milling activities, such as crushing, grinding, etc.,
(c) waste management

The parties (operators) in order to begin an activity they have to present an environmental impact assessment and an environmental impact statement must be obtained.

The purpose of the environmental assessment is to determine the potential impacts of a project on the physical, biological and socio-economic environment with a view towards determining mitigating measures for significant impacts and ultimately judging the acceptability of the project, balancing the potential impacts against the benefits.

4. CASE HISTORY

4.1. Malargüe Complex

In the framework of the national and provincial regulations it was necessary to develop a strategy to acquire the necessary technical knowledge in order to define the mining and milling uranium tailings management technology in the context of the whole criteria of radioactive waste management.

The final goal was to establish and implement the policies and procedures which will allow the proper management of this type of wastes within the limits imposed by the Radiological and Non Radiological Regulatory Authorities.

A general work plan resulting from the application of a block sequence technique to the basic investigations, needed to understand the problem and to determine the complementary research required, was established. It included the geological and hydrogeological characterization of the surrounding area of the facility, as well as the associated flora and fauna.

It analyzed quantitatively the radiological hazards to the members of the public and it was integrated with the safety assessment of non radiological hazards.

All relevant pathways that give rise to normal and potential exposures were identified and featured. Meteorological data as well as aquatic transport parameters were obtained and evaluated.

Once the possible dispersion extent is known, the limits of the disturbed ecosystem might be determined and compared with another undisturbed ecosystem to discriminate the potential effects produced by the tailings.

The unacceptable risks for the man and the environment were assessed and with all important variables known, the final assessment of the concurrent factors was completed.

Some potential solutions were analyzed in the framework of the following internationally accepted criteria:

(a) The dose limits specified by the Regulatory Authority should be observed.
(b) The annual releases of radioactive and non radioactive contaminants to the environment should be kept under the limits specified by the Provincial and Federal Authorities.
(c) Any exposure arising from the site must respect the ALARA principle.
(d) The options minimizing the institutional control and the maintenance should be preferred.
(e) The use of passive barriers to confine the contaminants should be maximized.

It was considered that the impoundment concept was consistent with the overall Argentine strategy for radioactive waste management, taking into account that it was the best and most widely used option to isolate the tailings from the environment.

Finally, the document "Environmental Impact Assessment and Long Term Management of the uranium tailings from the Industrial Complex Malargüe" came to the decision that the disposal of the wastes be kept in the same place with some relocations.

The basic and the detail engineering of the project have been finalized and they have been forwarded for the consideration of the provincial and federal authorities and presented in a public hearing to the population of the area. This project, which is of relevant importance, is being already executed.

4.2. Córdoba Complex

The uranium mill tailings that exist in the Córdoba Complex is an example where intervention criteria should be applied as in AR 10.1.1 standard.

⇒ Chronic exposure situation requiring remedial action to reduce or avert chronic exposure to radioactive wastes from past events.

ICRP Publication 60 in such a situation recommends the application of a protection system based on the following general principles:

(a) The proposed intervention should do more good than harm, i.e. the reduction in damage resulting from the reduction in dose should be sufficient to justify the harm and costs, including social costs, of the intervention.
(b) The form, scale, and duration of the intervention should be optimized so that the net benefit of the of the reduction of dose, i.e. the benefit of the reduction in radiation damage, less the damage associated with the intervention, should be maximized.

It is important to note that detrimental impacts due to mill tailings are not restricted to radiological hazards. Remediation activities, in general, have to address a variety of other potentially detrimental impacts. Important examples are:

(a) Physical hazards (e.g. failure of dams)
(b) Exposures to chemical substances, and
(c) Additional risks caused by the reclamation activities themselves, such as risks of traffic accidents while hauling large amount of material over public roads.

The long term uranium mill tailings management project is being currently carried out. The principals steps are:

(a) Site characterization and problem definition and, on this basis, assessment of currently prevailing and potential risks taking into account future changes;
(b) Identification of remedial and management options and evaluation of their risk reduction potential, costs and other relevant factors;
(c) Use of decision-making techniques such as cost-benefit analysis or multi-attribute analysis to decide the best waste management option in order to mitigate the impacts.

4. CONCLUSIONS

During recent years, there has been an increasing knowledge of the environmental and safety issues in mining and milling. Environmental impact assessments are now being carried out before starting up of new mines in most countries, including planning for mine and mill closure.

The new regulations in the safety field as well as the new environmental protection legislation in our country provide the frame for the technological decisions in the uranium mine and mill activities. Thus it will be possible in the future to avoid the very costly environmental restoration that is today being carried out at some sites where practically no precautions were taken during the planning or operation stages.

Nowadays, parallel with the continuing reduction of the mining of uranium ores, the remediation and decommissioning activities are becoming the main program of CNEA.

As many of these mines started before the environmental impact assessments were previously made, plans are being developed now in order to remedy these situations.

REGULATORY ASPECTS OF URANIUM REMEDIATION IN HUNGARY

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Abstract

In Hungary, there are numerous acts and decrees concerning the uranium ore mining remediation, including the aspects of radiation protection and release limits. The most important ones are: Mining Act, Atomic Energy Act, Environmental Protection Act, Water Management Act, Government Decrees No. 115/1993 and 152/1995. For radiation protection regulation the baselines are codified in the Hungarian National Standard MSZ 62/1–1989, while the release limits are prescribed in the order No. 3/1984 of Hungarian Water Authority (OVH), and in the standard MSZ 450/1–1989. According to the above documents, the limits for annual effective dose-equivalent are: (a) 50 mSv for persons occupied in nuclear industry or working with radioactive isotopes, this is relevant to mining and processing of uranium ore, (b) 5 mSv for the critical group of members of the public, in the case of long exposure this value could not exceed 1 mSv/a. In accordance to the EC directives, it is expected that the limit for the public will be decreased soon to 1 mSv/a. Release limits for discharge of natural radionuclides (U, Th, Ra, Rn) in surface water: (a) for uranium maximum 2 mg/dm^3, (b) for radium-226 maximum 1.1 Bq/dm^3. There are no general discharge limits for other pollutants in waste water, but the competent authorities may give individual limits if asked. Detailed limits are given only for drinking water for toxic and chemical components. Release limits for discharge of heavy metals are listed in order No. 3/1984 OVH. Of course, numerous licenses and permissions have to be obtained for remediation. The most important ones are the Environmental Protection Permission, based on a detailed environmental impact assessment, and the technical reclamation plans. Numerous authorities are involved in the licensing procedures (e.g. Mining Authority, Environmental Protection Authority, Water Authority, National Municipal Health Authority, etc.).

1. INTRODUCTION

In this paper the most recent and relevant laws, decrees and regulations, the regulatory authorities and organizations related to the remediation of uranium exploration sites, mining facilities and processing plants are reviewed. All the acts cited are available in [1].

ACTS AND DECREES:

1.1. Mining Act (N° XLVIII of 1993, supplemented and amended by N° XII of 1997)

Detailed regulation is codified in the *Government Decrees (Vhr.) N° 115/1993 (VIII. 12) and 132/1993 (IX. 29).* Further decrees signed by the respective minister are issued relating to different aspects of mining activity.

All activities related to the abandonment of mining (mine closure, reclamation) are so-called *mining activities,* which are defined in the § 1 of the mentioned *Mining Act*. Detailed regulation regarding these activities is given in the *Government Decree N° 115/1993 (VIII. 12)*. All activities belonging to this act can be carried out only with taking into account the protection of human life, health, environment, the property and the mineral and geothermic resources (§ 2). Mining activity can be started only if an appropriate permit is granted by the mining authority and if all conditions prescribed by the authority are fulfilled (§ 21) and based only on the mining claim fixed in its decision (§ 26).

The activity related to the mine closure has to be carried out according to the working plan approved by the mining authority (§ 27), the landscape rearrangement has to be fulfilled also according to a special plan (§ 36) approved by the mining authority. All underground mining workings can be left only in conditions which are not dangerous neither to their environment nor to the surface (§ 42). Requirements to the closing plans are listed in Vhr. (§ 26). The supervisory task and obligations of the mining authority related to the mining activity expires when the mining is finished and landscape rehabilitation is over with the exception of events defined in points 1/d and 1/g of the § 1.

1.2. Act of Atomic Energy (N° CXVI of 1996)

It should be noted that the new *Act of Atomic Energy* does not take into consideration the uranium ore mining and milling, because the substances generated from these activities from the point of view of this act (§ 2) are qualified as *not* nuclear substances. Some further decrees based on this act are now under preparation so in the future this act may also takes into consideration the planning and rehabilitation activities.

1.3. Radiation protection regulation

The general regulation with regard to the human activity connected with radioactive materials is given in *Hungarian National Standards, issued in 1989* under title *Protection Against Ionizing Radiation* (Hungarian Standard: *MSz 62/1-1989*) [2]. In this standard two limits are set for the annual effective dose-equivalent:

(a) *50 mSv* for persons working in nuclear industry or working with radioactive isotopes – this is relevant to mining and processing of uranium ore.
(b) *5 mSv* for a critical group of the public who are exposed to radiation, in addition to the natural exposure, but if this critical group is exposed to radiation close to this value of effective dose-equivalent for a long period, measures have to be taken to reduce the exposure to such a value that the total exposure of the critical group during its life time does not exceed *1mSv/a*.

Another important limit is the *annual limit of intake (ALI)* by ingestion and inhalation which is given for different radioactive isotopes taking into account the solubility and other properties of the compound of the given element. This value is used for approximate calculation of *derived limits of activity concentration (DC)* of given radioactive isotope in drinking water or in foods. These approximate calculations are carried out according to the equation below:

$$DC = (ALI / 200) \times (1/F),$$

where the values of *ALI* are given in the standard (ALI for $^{226}Ra = 2 \cdot 10^4$ Bq, for $^{238}U = 5 \cdot 10^5$ Bq, for *natural uranium* there is no direct limit), *F* is the annual consumption of water (550 l) or food (660 kg).

Derived limits for *radioactive isotopes in air (DAC)* are also given directly in the above standard: for ^{226}Ra this value is equal to 10 Bq/m^3, for ^{238}U it depends mainly on the solubility of the given compound.

At this time there is *no special standard related to rehabilitation, decommissioning works or rehabilitated areas*.

1.4. Act on water management (N° LIII and LVII of 1995)

Act LIII of 1995 on the general rules of environmental protection provides that used or waste water may only be discharged into environmental waters if natural processes are not endangered and if the renewal of the quality and quantity and the self purification, the reserves, the quality and the flora and fauna of the water remain free of any treat or adverse influence.

Act LVII of 1995 on water management provides that those entitle and have acquired the right to utilize water reserves shall on one hand ensure the security of the managed resources and on the other shall ensure that the waste water generated is collected, canalized and disposed of in accordance with the rules governing environmental protection.

According to the *Act (§ 28/1)* two steps of water management licensing procedure should be taking into account:

(a) First step is to get permission for building the appropriate water treatment installation, this is the so called establishment permission,
(b) The second step is the permission to operate the built water installation.

The Act gives the possibility for asking the so called admittance for the start of the planning of the establishment. The water management authority involves the respective environmental protection inspectorate and the local health authority in permitting procedure (these two authorities are involved as special authorities).

Beside this act, the *Government Decree N° 123/1997 (VII. 18)* on protection of drinking water aquifers is also important as this decree is related to the method of calculation of protecting zone of drinking water aquifer and gives information on the activities which can be performed at those areas. According to this decree, on the site of former mill of Mecsek Co., only very limited industrial activity can be carried out in the future as this site is situated on protected zone. This decree has to be taken into account when remediation works are planned, especially when further utilization of the mill site is planned.

1.5. Act on the general rules of environmental protection (N° LIII of 1995)

According to this act it is the responsibility of South-Transdanubian Environmental Protection Inspectorate to take measure if pollutants were released and spread. The *South-Transdanubian Water Authority* is responsible for the protection of the quality and quantity of surface and underground water from the effects of uranium mining and it should involve as special authority to the *South-Transdanubian Environmental Inspectorate* (with respect of the water quality) and the county *Institute of Public Health and Medical Officer Service* (with respect of radionuclides and ionizing radiation). So if the rehabilitation works are connected to water removal, water treatment, water discharge or the control of these activities, it is necessary:

(a) to get separate license from the water management authority,
(b) in addition, if this activity is connected with releases of pollutants, an environmental protection permit has also to be granted.

1.6. Laws regulating the technical and financial responsibilities for the remediation

In this respect special *Government Decision 2385/1997 (XI. 26)* was issued according to which the remediation works will be covered by the state budget.

2. RELEASE LIMITS

2.1. Emission limit values for discharge of natural radionuclides (U, Th, Ra, Rn) in surface water

For the company, emission limit values are set only for uranium and radium in discharged water. These limits are:

(a) for *uranium* maximum 2 mg/dm^3,
(b) for *radium-226* maximum 1.1 Bq/dm^3.

There are no limits for the other radionuclides. Likewise there are no limits for annual releases of the radionuclides.

2.2. Limits for other components

There are no general discharge limit values for pollutants in wastewater. In the *Decree N° 3/1984 (II. 7) OVH* (Hungarian Water Management Authority) which relates to the wastewater, the emission limit values are given only for those pollutants for which penalty has to be paid in case of exceeding the given emission limit values. However, according to this decree (§ 3/3) the competent authority may give individual limits if asked.

Detailed emission limits are given only for drinking water in standard *MSz 450/1-1989 for toxic and chemical components*. Limits for radionuclides can be calculated from the intake limit *(MSz 62/1–1989)* using the equation (1). By that expression, the limit for ^{226}Ra in drinking water is *0.63 Bq/l*, for ^{238}U that is *4.54 Bq/l* (0.36 mg/l). It should be mentioned that limits for *natural uranium* would be given in the near future.

Where more than one radioactive isotopes are present in the water or food, complex analysis of exposure ways is needed and the limits must be calculated from the results.

2.3. Release limits for discharge of heavy metals

Generally the limits listed in order *N°3/1984 (II. 7)* have to be taken into account.

2.4. Permissible gamma dose rate

As it was mentioned in the first part, at present the limits are (MSz 62/1-1989):

(a) *50 mSv/a* for persons who work in nuclear industry or working with radioactive isotopes, this is relevant to mining and processing of uranium ore.
(b) *5 mSv/a* for critical group of the members of the public, in addition to natural exposure, but if this critical group are exposed close to this value of effective dose-equivalent for a long period, measures have to be taken to reduce the exposure to such a value that total exposure of the critical group during its live time does not exceed 1mSv/a.

In accordance with EC directives, it is expected that the limit for public will be decreased soon to *1 mSv/a*.

3. LICENSING PROCEDURE

3.1. General remarks

In Hungary, most human activities are regulated by provisions of law. The primary sources of law are the acts codified by the Parliament, but in numerous cases the Government or the Ministers received authorization from acts to make more detailed regulations for certain types of activities. The execution of provisions of law is done and inspected by the state administration, i.e. the authorities.

The system of state administration has two levels. The first level is represented by regional authorities, the second level by supreme authorities. The authorities can get sphere of authority only from provisions of law (acts, Government or Minister decrees). The authorities can act only on the basis of law. If a client doesn't agree with the decision of a regional authority, it can appeal to the superior authority. The decision of the superior authority can be brought to trial of the court.

The system of state administration is organized on the basis of professional specialty. The regional authorities are subordinated to the supreme authorities from professional and organizational point of view, but they are independent in the process of making decisions. All regional authorities have a geographical area of competence declared by law. All supreme authorities have national competence, of course in the given special field.

The proceedings of authorities are regulated by the Act of General Rules for State Administration. If a case affects the sphere of another authority, the client or the authority that makes the final decision has to obtain the approval of the other authority, which is called special authority in this case. An authority can be a decisive authority or special authority as well, depending on the given case. The authority that makes the final decision should include the approvals of the special authorities into the decision.

In the procedures related to the abandonment of uranium ore mining and to the reclamation of sites, the following authorities can be (or must be) involved (main important acts are also given — in some cases they are repeated):

Regional office of the mining bureau of Hungary

Regional office: Pécs District Office of the Mining Bureau of Hungary. Responsible for inspection of all mining activities (prospecting, exploration, mining, reclamation, etc). Makes final decision in most of licensing procedures related to mining, keeps register on mining areas. Regarding this field the main regulations are the *Mining Act (Act N° XLVIII of 1993)* and the *115/1993 (VIII. 12) Government Decree*.

Regional water authority

Regional office: South-Transdanubian Regional Water Authority. Responsible for protection and management of all water resources (surface and underground). Its contribution as a special authority is compulsory in most of the licensing procedures related to mining *(§ 13 of the 115/1993 (VIII. 12) Government Decree)*. Relevant main regulations are: *Water Management Act (N° LVII of 1995), 72/1996 (V. 22), Government Decree* and the *18/1996 (VI. 13) Decree of the Minister of Transport, Communication and Water Management*.

Regional environmental protection authority

Regional office: South-Transdanubian Environmental Inspectorate. Responsible for protection of environmental media. Relevant main regulations are: *Environmental Protection Act (N° LIII of 1995), 152/1995 (XII. 12) Government Decree*.

Nature conservation authority

Regional office: Danube-Drava National Park Directorate. Responsible for protection of natural vegetation, animals, geological formations and landscape. Relevant main regulation is the *Nature Conservation Act (N° LIII of 1996)*.

National health and medical officer service

Regional office: Baranya County Institute of Public Health and Medical Officer Service. Responsible for protection of health of human environment. Relevant main regulation is the *Act N° XI of 1991*.

Forest service

Regional office: Pécs District Office of the Forest Service. Responsible for suitable and safe forest management, for the forests as resources. Relevant main regulation is the *Act N° LIV of 1996*.

Hungarian geological survey

Regional office: South-Transdanubian Office of the Hungarian Geological Survey. The Geological Survey has to give expertise in many cases related to geology, including mining. Relevant regulation is the *132/1993 (IX. 29) Government Decree.*

Office of land management

District office: Pécs District Office of Land Management. Responsible for protection of agricultural land, keeps register of land properties. Relevant main regulation is the *Act of Land (N° LV of 1994)*.

Municipalities

Give licenses for construction of buildings, and are responsible for fire protection. The public can participate in the procedure.

In some special cases the *Transport Inspection Authority* and the *Communication Inspection Authority* also can contribute to the permitting procedure.

The authorities are supervised by their respective ministries. The Mining Bureau of Hungary and the Hungarian Geological Survey belong to the *Ministry of Industry, Trade and Tourism*. The Environmental Inspectorate and the Nature Conservation Authority are supervised by the *Ministry for Environment and Regional Policy*, while the Water Authority by the *Ministry of Transport, Communication and Water Management*. The Municipal Public Health Service belongs to the *Ministry of Welfare*, the Forest Service and the Office of Land Management belong to the *Ministry of Agriculture*. The Municipalities are supervised by the *Ministry of the Interior*.

Beside these authorities, there are independent institutes that are not authorities, but their studies or statements often serve as basis of decisions of the authorities. Such an institute is for example the *National "Frédéric Joliot-Curie" Institute for Radioprotection and Radiobiology* which gives its recommendations for radiation protection issues.

3.2. Steps of licensing procedures related to the remediation of uranium ore mining and processing sites

All activities related to the abandonment of mining (mine closure, reclamation) are so-called *mining activities,* which are defined in the § 1 of the Mining Act. The procedure to be followed is described below.

First step

The licensing procedure of the *remediation* has to be preceded by an environmental protection licensing, which is an entirely independent procedure of the Environmental *Inspectorate (§ 67 of Act N° LIII of 1995)*. This license will be based on a detailed environmental impact assessment submitted by the Mecsek Ore Environment Co.

The detailed rules of environmental licensing is prescribed in the *152/1995 (XII. 12) Government Decree (Vhr)*. Appendix 1 of this decree refers to uranium ore mining as an activity which has to be licensed by the Environmental Protection Authority, not only before starting of mining, but in the case of abandonment as well. In the licensing procedures numerous authorities as special authorities should participate (e.g. Nature Conservation Authority, National Municipal Health Service, Municipalities, etc). The result of this procedure provides the company with the *Environmental Protection License* for remediation.

Second step

After getting the environmental protection license, the licensing procedure at the *Pécs District Office of the Mining Bureau of Hungary (Mining Act § 43-44, Vhr. § 27-28)* can be started. In this case the licensing means approval of remediation plan.

It can be a prepared comprehensive remediation plan or several more independent ones for waste rock piles, tailing ponds, heap leaching piles, etc. Usually the general rehabilitation plan is fulfilled step by step. That is why annual technical operation plans should be prepared and approved. The minimum requirement for a technical operation plan is listed in the *§ 13 of Vhr*.

Parallel with this licensing procedure an additional *water management licensing procedure* has to be started if the planned remediation works effect in some way the water pathways. The appropriate plans must be submitted to the *South-Transdanubian District Water Authority*.

The special authorities which should be involved in the licensing procedure were listed earlier. Two new acts, the *Act on the General Rules of Environmental Protection (N° LIII of 1995)* and the *Nature Conservation Act (N° LIII of 1996)* assure wide sphere of authority for the competent authorities, so the interests of the protection of the environment and nature can be enforced.

A report should be prepared on the ore reserves that will be left underground. This report should be submitted to the *Hungarian Geological Survey (Mining Act § 25)*. When the abandonment and reclamation activities will be ready, the mining plots have to be deleted from the register of the mining authority and of the land management office. Some liabilities of the mining company (e.g. monitoring, compensation for damages caused by mining, etc.) will remain after deleting the mining plot from the register.

3.3. Authorities responsible for supervising, the execution and results of remediation plans and measures and low enforcement

It should be mentioned that there are some authorities supervising the remediation plans, but the mains are:

(a) Pécs District Office of the Mining Bureau of Hungary,
(b) South-Transdanubian Environmental Inspectorate,
(c) South-Transdanubian Water Authority,
(d) Baranya County Institute of Public Health and Medical Officer Service.

All activities are supervised by the *Ministry for Environment and Regional Policy* and the *Ministry of Industry, Trade and Tourism*, representatives of which have the right to take part in tender procedure for specific remediation measures as well.

Licensing procedure in the case of Mecsek Ore Environment Co.

The remediation work started by compiling the concept for remediation. This work was carried out without any legal binding, but was important to give account of activities to be carried out during the remediation. On the bases of this document a rough estimation of the cost of remediation was given.

This document was sent to all important authorities and to the *Ministry for Environment and Regional Policy* asking for their comments. Taking into account the remarks sent to Mecsek Co. and the concept of the proposal itself, the investment proposal was elaborated for *National Privatization and State Holding Company*, for compiling submission to Government asking it for decision and arranging the financial needs of remediation.

On the basis of the remediation concept environmental impact assessment was compiled and submitted to the *South-Transdanubian Environmental Inspectorate*. This authority distributed this document among competent special authorities and all concerned local authorities asking for their comments. This procedure will be finished by the issuing of the *environmental protection license for remediation*.

On the basis of this document, the licensing procedure for carrying out real work (relocation of waste rock piles, demolishing of buildings, closing mine workings etc.) can be started *at Pécs District Office of the Mining Bureau of Hungary*. It has to involve the *South-Transdanubian District Water Authority* in the procedure as special authority. Other authorities that are to be involved in the procedure depends on the decision of the *District Office of the Mining Bureau of Hungary*.

The Authority gives permission for work indicated in the annual technical plan. The annual technical operating plan should be in full compliance with the environmental protection license. For each remediation activity (relocation of wastes, covering the damps, demolishing of buildings etc.) separate permission has to be obtained additionally, but this activity has to be mentioned in the annual technical operating plan as well.

For the time being a separate document for *water utilization license* is under preparation, which has to be submitted to the *South-Transdanubian District Water Authority*. In this document all important water collecting, water treatment, water discharging issues will be addressed.

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THE REGULATORY ROLE OF THE HUNGARIAN GEOLOGICAL SURVEY IN THE CLOSURE OF MECSEK URANIUM MINE

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Abstract

Under Mining Act XLIII established in 1993, the Hungarian Geological Survey was given a wide range of authority related to the environment, mining, nuclear and general constructions. In implementing these task the Survey will be supported by the well established Geological Institute of Hungary and the Eötvös Loránd Geophysical Institute. The Survey's role in the nuclear field includes the licensing of plans and reports on geologically related research to any nuclear facilities. The Hungarian Geological Survey is also co-authority on matters related to the establishment, construction, modification and closure, environmental protection of nuclear facilities in general and all matter related to uranium mining. The Survey's regulatory activity in radioactive waste management follows the Decree of the Minister of Industry and Tourism 62/1997 which is based on the Atomic Energy Act CXVI of 1966. These regulations were prepared in harmony with the OECD Nuclear Energy Agency and the International Atomic Energy Agency conventions, standards and guides and those of other countries. Case histories on the applications of these regulations to the closure of Mecsek uranium mine and the operation of the research laboratory tunnel for long-lived, high level radioactive waste are presented here.

1. INTRODUCTION

The Hungarian Geological Survey (hereinafter referred to as "Survey") established in 1993 by the XLVIII. Mining Act has wide and sound regulatory rights and related tasks in many fields as environmental, mining, nuclear and construction affairs. The regulatory measures are accompanied by public service (mostly geological data service) and backed up by research activities of its financially independent institutes, the 130 years old Geological Institute of Hungary and the 80 years old Eötvös Loránd Geophysical Institute. The Survey performs all the above-mentioned three functions in the nuclear field, details of the regulatory side are presented hereby.

2. REGULATORY RIGHTS AND PRACTICE

The Survey's expert authority rights are established in the 132/1993 (IX.29) Government Decree. This Decree defines the competency of the Geological Expert Authority in licensing procedures by citing the relevant legal acts and gives the general outline that the seven Regional Offices should act in the first degree proceedings. In case of declined applications the client can appellate and initiate a second proceeding at the Geological Expert Authority. The total number of cases that were proceeded at the Survey was 1939 in year 1997. Most procedures were related to mineral exploration, mining and environmental affairs, less expertise was issued in land use planning, nature protection, construction licensing, etc. The spatial distribution of cases reflect the different development of the counties, where there are more cases in the western part of Hungary.

The Survey's regulatory mission is three-fold:

(a) to protect the geo-environment against the unfavourable human impacts (e.g. contamination by hazardous wastes);
(b) to protect the human environment against geo-hazards (e.g. landslides, earthquakes, liquefaction of soils);
(c) to protect mineral resources and to promote their sustainable exploitation.

The object of the Survey's regulatory work is the geo-environment (lithosphere) which can be defined as the complex totality of the solid, liquid and gaseous phases of the Earth's subsurface. The subject of this expert activity is the interaction between geo-environment and human activity in general which demands a dynamic way of interpreting and evaluating these complex, time-dependant processes.

The regulatory attitude of the Hungarian Geological Survey is a performance-based approach. This approach and practice involves that no or just a few prescriptive, quantitative standards and requirements are forced and the licensee is required to comply with the given objectives and measures with a certain freedom to achieve. The Hungarian law gives a chance for the communication between the client and the authority that is a frequent practice at the Survey.

3. ROLE IN THE NUCLEAR FIELD

The Survey's regulatory role in the nuclear field is multiple. It is the licensing authority of plans and final reports of geological research related to nuclear facilities in general (power plants, research reactors, waste disposals) and the recording authority of all the nation's mineral resources and reserves including uranium ore reserves as well.

The Survey is a licensing co-authority in

(a) establishment, construction, modification and closure of nuclear facilities in general;
(b) environmental protection licensing of nuclear facilities (reviewing environmental impact studies, performance assessments and audits);
(c) uranium mining affairs (reviewing research plans and reports, annual technical plans, remediation plans, opening and closure plans of mines).

The co-authority role means that the Survey's expertise has to appear in the final decision of the licensing authority (e.g. in that of the Environmental Inspectorate).

The basic legal act encompassing and governing the Survey's regulatory activity in radioactive waste management is the Decree of the Minister of Industry, Trade and Tourism 62/1997 (XI.26) on the Geological and Mining Requirements for the Siting and Planning of Nuclear Facilities and Radioactive Waste Disposal Facilities in accordance with the Act CXVI of 1996 on Atomic Energy.

This Decree gives the most important definitions (e.g. geological barrier, potential site, institutional control, etc.), the methodology and geological requirements of site selection and characterisation, the essential elements of quality assurance and control, the general geological and mining requirements, details of the licensing procedure, and in four appendices the special geological requirements for siting of (1) nuclear facilities; (2) deep geological disposal facility for high-level radioactive waste; (3) deep geological disposal facility for low- and intermediate-level radioactive waste; (4) surface and near-surface disposal facility for low- and intermediate-level radioactive waste. A special procedure appears in the Decree that the applicant may request a preliminary expert opinion of the Survey prior to commencement of the licensing procedure.

These regulations were set in harmony with the OECD Nuclear Energy Agency and the International Atomic Energy Agency conventions, standards and guides, and the relevant regulations of some countries (e.g. France, Finland, USA, Germany, Japan, etc.) were considered as well.

4. REGULATORY ROLE IN THE CLOSURE OF MECSEK URANIUM MINE

4.1. Mecsek uranium mine

The Mecsek Uranium Mine was in operation between 1956 and 1996. It had six mining plots (65 km^2) which covers 18 Mm^3 underground space, 1.5 Mm^3 is still open. Its facilities were thirteen shafts, one enrichment plant, two leaching heap piles (47 ha, 400 t U), two tailing ponds (20.3 Mt slurry, 1330 t U) and ten waste rock piles (9.8 Mm^3, 1030 t U).

4.2. Environmental licensing

As a licensing co-authority the Survey's South Transdanubian Regional Office (hereinafter referred to as "Office") reviewed the preliminary and detailed environmental assessment studies of the mine closure. It required quantitative data of uranium, other radioactive elements and their daughter isotopes in form of documented, balanced equations considering exploitation, milling and enrichment activities, export and disposal. The Office asked for the geochemical characterisation of the tailings and slurries (e.g. sulphate, heavy metals, radiochemicals), and for an assessment of how these elements and compounds are fixed or can migrate to the surface or to groundwater reserves.

Another conflict field was the protection of the potable groundwater reserves of Pécs. The Neogene aquifer system is in direct communication with the partially contaminated groundwater of the Late Palaeozoic - Mesozoic rock formations. The preliminary impact assessment did not study this problem in depth. A detailed study and a hydrogeological monitoring system was prescribed.

According to the recharged groundwater level rise and the high volume of loose underground spaces the Office requested for a geomechanical study to assess future surface movements that can jeopardise buildings and other facilities. Additional geomechanical monitoring system was prescribed. The Office criticized the planned design of the soil cover for the leaching heap piles which was not appropriate from radiation protection nor from erosion protection point of view.

4.3. Technical plans

The annual technical plans of exploitation and technical plans of closure and remediation were reviewed by the Office. The Office required to submit the complete mining geological documentation including the maps of the latest operation phase and the maps of the exploration facilities (e.g. boreholes, geophysical profiles, etc.). The Office missed the detailed accounts of mineral resources exploited. Moreover it required to prepare and submit a final summary report of the geological exploration works carried by the Company.

4.4. The future of "α" test tunnel

The Boda Siltstone Formation, a potential host rock formation for high-level radioactive waste, has been studied in a tunnel of Mecsek Uranium Mine as an underground laboratory since 1993. This low porosity and permeability, pelitic formation underlies the uranium-rich Upper Permian — Lower Triassic red sandstone formation which was exploited in the mine. This test tunnel was constructed and furnished with the most up to date equipment to study in situ the hydrogeological, geochemical, mineralogical-petrological and geomechanical properties of the formation as a potentially suitable one to accommodate long-lived, high-level radioactive waste.

The annual research reports are generally accepted by the Survey without any serious objections due to the high quality of scientific performance. The future of the underground laboratory is a function of the details of closure of the mine because the survival of the two shafts needed for the operation is a financial problem.

5. CONCLUSION

Being the basic and most complex earth science, geology is a base to assess and judge subsurface material processes - including radioisotopic processes (e.g. sorption, migration, etc.) - that can effect human environment. Understanding this the Hungarian Parliament and Government gave sound regulatory rights to the Hungarian Geological Survey in many licensing procedures. According to the professional attitude, the Survey's expert opinions were decisive in many cases. The multiple regulatory functions of the Survey prevail in the nuclear field and especially in the closure of Mecsek Uranium Mine as well. This may help to minimize the risk of unfavourable impacts on present and future populations living there.

THE IMPACT OF ENVIRONMENTAL AND SAFETY REGULATIONS ON THE URANIUM MINE ZIROVSKI VRH SITE REMEDIATION

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Abstract

The development, adoption and enforcement of a new, post-independence Slovene legal system have not been completed. Also, the regulation of the Republic of Slovenia on nuclear safety and protection against ionising radiation is based on former Yugoslavia legislation, the regulative on the environment protection is based on new Environmental Protection Act, issued in 1993. A new proposal of the Law on Safety against Radiation is under preparation which is co-ordinated by the Ministry of Health. The proposition of a new nuclear safety and nuclear energy legislation will be prepared with the concern of the Ministry of Environment and Physical Planning i.e. Slovenian Nuclear Safety Administration. Remediation of the site of a former uranium producer Uranium Mine Žirovski Vrh is managed by the Law on Permanent Close-out of Uranium Ore Exploitation and Prevention on Mining Consequences at the Žirovski Vrh Uranium Mine. The mine received the location permit in 1979, operating permit in 1984 and 1985 (start up and permanent operation). In Slovenia three permits are necessary to carry out a new project or to close-out the mine respectively. All to be issued by the Ministry of Environment and Physical Planning: a location permit, a building permit and an operation permit. Environmental impact assessment has to be completed before a location permit can be delivered, for those projects for which the environmental impact assessment is mandatory.

1. INTRODUCTION

Slovenia is a central European country, located along the foothills of the eastern end of the Alps, at the very tip of the most northern Mediterranean bay. The Žirovski Vrh Uranium Mine had started yellow cake production in September 1984 which stopped in June 1990. The company has been managing the site maintenance and remediation activities since that time.

The development, adoption and enforcement of a new, post-independence Slovene legal system have not been completed. During the transitional phase all previous laws remain in force. Also, the regulation of the Republic of Slovenia on nuclear safety and protection against ionising radiation is based on former Yugoslavia legislation [1, 2]. The regulation on the environment protection is based on new Environmental Protection Act, issued in 1993 [3]. This fundamental law governs environmental policy, and passed regulations are more demanding and is in accordance with European policy in this field [see Annex I].

A new proposal of the Law on Safety against Radiation is under preparation co-ordinated by Ministry of Health (MoH) [4]. This will cover ionising and unionising radiation. The preparation of a new nuclear safety and nuclear energy legislation will be prepared with the concern of the Ministry of Environment and Physical Planning (MoEPP) i.e. Slovenian Nuclear Safety Administration (SNSA).

Also, a new Mining Law is currently in the parliament procedure. From this a new, up to date, regulation will be developed for technical and safety in working areas.

By the Act on Organisation and Working Field of State Administration, control over performance of the nuclear laws and regulations is entrusted to the SNSA and performance of the laws and regulatory protection against radiation is entrusted to the Health Inspectorate of the Republic of Slovenia (HIRS) which is part of MoH [5]. In the case of mine, Mining Authorities and Republic Mining Inspectorate (RMI) are also involved [6]. Since it also belongs to their field competencies responsibility is also given to Environmental Inspection, Fire Inspection, and Energy Inspection (electrical power, steam, etc.).

2. PERMITS AND ENVIRONMENTAL IMPACT ASSESSMENT

In Slovenia three permits are necessary to carry out a new project or to close-out a mine. All are to be issued by MoEPP: a location permit, a building permit and an operation permit. Environmental Impact Assessment (EIA) has to be completed before a location permit can be delivered, for those projects for which the EIA is mandatory. Figure 1 schematically presents the system of permits including EIA procedure for obtaining all three permits [8]. Practically all authorities e.g. local and national are involved in the licensing procedure for uranium liabilities and have to give their consent to the proposed plans. In the case of emergency (e.g. landslide) this procedure is simplified. Since the Žirovski Vrh mine and mill operation permits were issued years ago, and did not include remediation plans approvals. Nowadays, it is clear that the site remediation plans must also pass the request for location and building permit.

Remediation of the site of a former uranium producer Uranium Mine Žirovski Vrh is managed by the Law on Permanent Close-out of Uranium Ore Exploitation and Prevention on Mining Consequences at the Žirovski Vrh Uranium Mine [7]. The mine received the location permit in 1979, operating permit in 1984 and 1985 (start up and permanent operation).

Application for the location permit for the remediation of the whole uranium mine exploitation area had been submitted to the authorities in 1995, which include Environmental Impact Report [9]. This permission obtaining procedure has been stalled since SNSA questioned the proposed mill tailings siting solution, e.g. the existing place. They have strongly requested additional safety evaluations of the long-term location of the mill tailings. However, partial location permit for the mine and mill surface decommissioning had been granted to the Žirovski Vrh Mine (not for mill tailings and mine waste rock pile Jazbec) in 1996, and the company obtained the construction permit (1997) and implementation has started [14].

Authorised limits

An authorised limit was granted for an effective dose of 0.3 mSv/a as a contribution to the critical group from the remediated site by the HIRS [12]. Authorised limits of radioactive contaminants for different emission and recipient points were given in the same document and are shown in Table I. Restrictions were given as concentration limits in effluents and as yearly mass flow of the contaminants in the water stream. American regulation (Regulatory Guides) had big influence on issuing the procedure.

Comparison among figures given by the regulations and by the authorised limits is given in the Table II [13]. From the table of comparison it is evident, that there is a hole in the regulation. Modern and improved regulation is needed in this field.

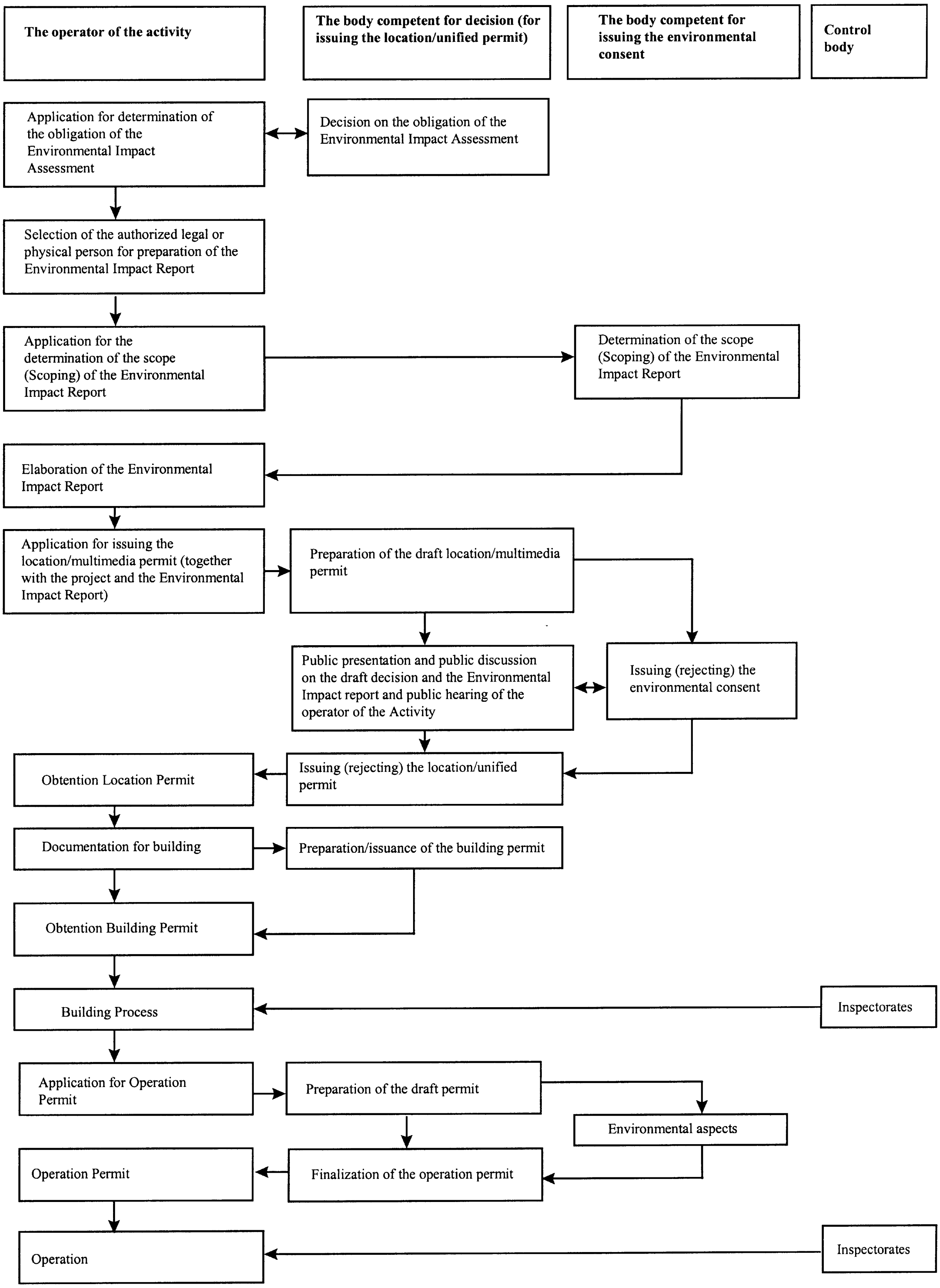

FIG. 1. System of permits including EIA procedure (from Environmental performance Reviews - Slovenia).

Practical work

At practical work IAEA's recommendations are used regardless of the obsolete regulations. For professional exposure e.g. the effective dose of 50 mSv/a is prescribed, yet the effective dose of 20 mSv/a is in use. Prescribed effective dose of 1 mSv/a for public, is obeyed in practise.

TABLE I. AUTHORISED LIMITS

	Uranium		Radium 226		Other
	μg/L	kg/year	Bq/m^3	MBq/year	Bq/m^3
Emission control point					
Run off mine water	250	170	60	50	
Mine waste disposal drainage water	510	85	40	25	100[a]
Mill tailings ^{222}Rn exhalation rate					0.7[c]
Mine waste disposal site ^{222}Rn exhalation rate					0.1[c]
Unrestricted area gamma dose rate					0.2[d]
Recipient control point					
Todra〉 Brook - collector of all mill tailings waters			60	50	
Brebovščica River - collector of all Žirovski mine area waters	50[b]		40		

Note:
a) Sum of activities of Thorium 230, b) Limit for uranium in potable water (chemical)
c) Different Rn-222 exhalation rates due to different location, d) μGy/h

TABLE II. COMPARISON OF THE REGULATIVE LIMITS

	Authorised limits			Regulations	
	Uranium μg/L	Radium Bq/m^3	Radon[a] Bq/m^{2}s	Uranium μg/L	Radium Bq/m^3
Emission control point					
Run off mine water	250	60		NA	NA
Mine waste disposal drainage water	510	40		NA	NA
Mill tailings ^{222}Rn exhalation rate			0.7		
Mine waste disposal site ^{222}Rn exhalation rate			0.1		
Recipient control point					
Todra〉 Brook - collector of all mill tailings waters		60			1000
Brebovščica River - collector of all Žirovski mine area waters	50[b]	40		50[b]	1000
Dose rate to the critical group of public	0.3[c]			1.0[c]	

Note:
a) Radon 222 exhalation rate
b) Limit for uranium in potable water (chemical)
c) Effective dose rate in mSv/a

Table III shows the effective dose rate (contribution to the critical group) from 1991 till 1997. With the designed engineered remediation works for mill tailings and mine waste pile the dose contribution will be decreased from 0.3 - 0.4 mSv/s to under 0.3 mSv/a.

TABLE III. EFFECTIVE DOSES SINCE CLOSE-OUT OF THE MINE AND MILL FACILITIES

Year	1991	1992	1993	1994	1995	1996	1997
Effective Dose (mSv/a)	0.34	0.34	0.29	0.33	0.37	0.32	0.30

3. INTERPRETATION

There are also different opinions regarding the responsibilities and interactions of the two governmental administrative bodies: RMI and SNSA due to different explanations of the regulations.

Regulation from the mining law have regulated the mine wastes and mill tailings management: Regulation on Technical Norms for Research Exploitation and processing of Nuclear Mineral Primary Materials and Regulation on Technical Norms for Surface Exploitation of Ore deposits defines what are wastes and how to manage them [10, 11]. Operation permit for mill tailings was issued by mining authorities. SNSA claims that mine waste pile and mill tailings are nuclear facilities and have to be managed by the regulation based on nuclear safety law. These means that permitting procedures and decommission must be the same as for nuclear waste storage facilities. Operating licence (permit) is under question, because it might be issued by incorrect governmental body (RMA instead of SNSA).

The Žirovski Vrh company asserts that the mine wastes and mill tailings have to be and can be safely managed by the mining regulation, obeying also up to date radiation protection principles. Managing the mine wastes and the mill tailings the same way as nuclear waste is too expensive and cannot be justified.

The problem in obtaining the location permit process was the landslide under the mill tailings site. It has now been stopped and stabilised. However, long-term maintenance and satisfactory stability is a part of this dispute. The consequence is that SNSA doesn't give the consent to the location permit for these two objects.

4. CONCLUSION

Radiological impact of the remediated objects will be without any doubts are within regulated and authorised limits. The real problem is how to maintain long-term mechanical integrity of the mill tailings site and mine waste pile due to natural forces. Regulation on Technical Norms for Surface Exploitation of Ore Deposits determines mechanical and geo-mechanical quantities which must be achieved [15].

Not part of this discussion, but has to be mentioned, is the influence of chemical pollutants in the effluents on surface waters. This impact is less attractive but more important than radiological since they are exceeding some norms, regardless whether they are old or new norms.

The most urgent and critical problem in the whole mine decommissioning schedule is obtaining the location permit for the remediation of the mill tailings and mine waste pile. New application for mill tailings and mine waste with the requested completion will be presented to the governmental agency.

REFERENCES

[1] Act on Radiation Protection and the Safe Use of Nuclear Energy (Off. Gaz. SFRY, No. 62/84).

[2] Act on Implementing Protection against Ionising Radiation and Measures for the Safety of Nuclear Facilities (Off. Gaz. No. 28/80).

[3] Environmental Protection Act, (Off. Gaz. No. 1993.

[4] Law on Safety against Radiation (Proposal, April 4, 1998, in Slovene).

[5] Mining Law (Off. Gaz. SRSNo. 17/75 in Slovene).

[6] Act on Organisation and Working Field of State Administration, (Off. Gaz. No. /91, in Slovene).

[7] Law on Permanent Close-out of Uranium Ore Exploitation and Prevention on Mining Consequences at the Žirovski Vrh Uranium Mine (Off. Gaz. No. 36/192).

[8] Environmental Performance Reviews - Slovenia, United Nations 1997.

[9] Lenart et al., Report on the Effects on the Environment while Caring out the Programme on Close-out of the Mine and the Programme on Preventing the Consequences of the Mining, RZV, 1995 (in Slovene).

[10] Regulation on Technical Norms for Research Exploitation and processing of Nuclear Mineral Primary Materials (Off. Gaz. SFRY 39/85, 40/86 in Slovene).

[11] Regulation on Technical Norms for Surface Exploitation of Ore deposits (Off. Gaz. SFRY 4/86 in Slovene).

[12] Ministry of Health, Health Inspectorate of the Republic Slovenia, Former Consent to the Location Documentation, (24 April 1996 in Slovene).

[13] Regulation on Maximal Limits for Radioactive Contamination of the Human Environment and on Decontamination Z-9 (Off. Gaz. SFRY 8/87).

[14] Partial Location Permit (MoEPP, Ljubljana, 18.10. 1996.

[15] Regulation on Technical Norms for Surface Exploitation of Ore Deposits (Off. Gaz. SFRY 4/86).

ANNEX I

List of the Valid Slovenian Laws, Regulations and Ordinances in Connection with Uranium Mine Žirovski Vrh Remediation (September, 1998).

1. CONSTITUTION

Constitution of the Republic Slovenia - URS (RS 33/91-I)

2. MINING LAWS

Mining Act (SRS 17/75)

3. ATOMIC LAWS / RADIATION PROTECTION ACTS

On protection from ionizing radiation and on nuclear safety – ZIVIS (RS 28/80, 32/80)
On radiation protection and the safe use of nuclear energy -ZVISJE (SFRY 62/84) translated
On liability for nuclear damage – ZOJS (SFRY 22/78, 34/79) translated
On transportation of dangerous materials – ZPNS (SFRY 27/90)
On energetic economy
On organization and field of activity of the administration (RS 20/91)

Some other acts that also deals with radioactivity in minor part

On Hydrological and Meteorological Activities Important for the Country – ZHM (SFRY 18/88)
On Working Posts, where Pension Age is Numbered by Amplification (SFRY 17/68, 20/69, 29/71)
On Remedy Traffic (SFRY 43/86)
On Health Blamelessness of Food and Subject Matter of General Use (SFRY 55/78, 58/85)
On Units of Measurements and Measuring Tools (RS 1/95),
The Law on Road Transportation (RS 72/94),
The Law on Standardization (RS 1/95),
The Law on Ratification of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (RS /93),

4. REGULATIONS/GUIDELINES/DECREES/DIRECTIVES

4.1. Based on mining act

Regulation on Technical Norms for Research, Exploitation and Processing of Nuclear Mineral Primary Materials (SFRY 39/85, 40/86) minor part translated
Regulation on Technical Norms for Surface Exploitation of Ore Deposits (SFRY 4/86)
Regulation on Professional Education and Qualification of Technical Managers, Managers of Technical Services and Technical Supervision Personnel at Exploration or Exploitation of Ores and Professional Licenses and Adequate Experiences of Senior Designers of mining Objects (SFRY 14/76)
Regulation on Exploration and Exploitation Areas of Minerals (SRS 23/76)
Guideline on Records Keeping and Register of the Exploration and Exploitation Areas (SRS 9/77)
Regulation on Technical Norms on Mining Measurements, Measurement Books and Mining Drawings (SFRY 50/66)
Regulation on Classification and Categorization Reserves of Primary Materials and their Evidence (SFRY 50/66)

Regulation on Content of the Mining Drawings for Solid Minerals Exploitation (SFRY 21/68)
Guideline on Process Operations for Enrichment and Dressing of Primary Minerals (SFRY 51/59, 1/60)

Regulation on Technical Norms for Enrichment of Primary minerals – Nonferrous Ores (SFRY 36/79)

4.2. Based on radiation protection acts/atomic acts

Regulation on sites, method and time limits for Examinations of Contamination by Radioactive minerals – Z1 (SFRY 40/86) translated
Regulation on the Mode the Extent and the Limits of the Systematic Examinations of Radioactive Material Contamination in the Surroundings of Nuclear Facilities – Z2 (SFRY 51/86) translated
Regulation on the Mode of Collecting, Accounting, Processing, Storing, Final Disposal and Release of Radioactive Waste into the Environment – Z3 (SFRY 40/86) translated
Regulation on Limits that Must not be Exceeded by Radiation to which the Population and Those that Work with Sources of Ionising Radiation are Exposed, on the Measurement of Decree of Exposure to Ionising Radiation of Persons that Work with the Sources of these Radiation and on the Testing of the Contamination of the Working Environment – Z6 (SFRY 31/89) translated
Regulation on Maximal Limits of Radioactive Contamination of the Human Environment and on Decontamination Z-9 (SFRY 8/87)
Regulation on the Condition for Siting, construction, Commissioning, Commencement of Operation and Operation of Nuclear Facilities – E1 (SFRY 52/88) translated
Regulation on Compilation and Contents of the Safety Report and other Documentation Necessary for the Assessment of the Safety of Nuclear Facilities – E2 (SFRY 68/88) translated
Regulation on Professional Education, Working experiences, Testing of Knowledge and the Certificate on Fulfilled Condition for Persons Performing Certain Works in Nuclear Facilities – E3 (SFRY 86/87)
Regulation on Material Balance Areas and on the Mode of Keeping Records on Nuclear Materials and on the Dispatch of Data from these Records – E4 (SFRY 9/88)
Directive on Temporary Stop of Exploitation and Exploration of Uranium Ore in Uranium Mine Žirovski Vrh (RS 40/90)

4.3. Based on other acts that also deal with radioactivity in minor part

European Agreement Concerning the International Carriage of Dangerous Goods by Road (SFRY 61/79) - translated
Dangerous Goods Regulations (IAEA/ICAO/IATA n.a.).
On Quality of Natural Mineral Water (SFRY 58/78)
Decree on Classification of the Republic Water Flows, International Waters and Waters of the Coastal Sea of Yugoslavia (SFRY 6/78)

5. WATER PROTECTION LAW

The environmental protection act – ZVO (RS 32 /93, 1/96) translated
The law on waters (RS 38/81)

5.1. General regulations

Decree on Type of Interventions into Environment for which the Environmental Impact Assessment is Mandatory (RS 66/96)

Instruction on Methodology for Environmental Impact Report Preparation (RS 70/96 Decree on Export, Transport and Transit of Waste (RS 39/96)

Statue on the Handling of Special Waste Containing Dangerous Substances (RS 20/86, 4/89, 39/96).

5.2. Water protection regulations

On Hygienic Blamelessness of Drinking Water (SFRY 33/87)

Water protection regulations of Chemotoxic elements/release limits

Regulation on the First Measurements and Operational Monitoring of the Waste Waters and on Conditions for Implementation (RS 35/96)
Directive on Material Emission in the Discharge of Waste Water from Municipal Water Treatment Plants (RS 35/96)
Directive on Materials and Heat Emission in Discharging from Pollution Sources (RS 35/96)
Directive on Taxes for Water Pollution (RS 41/95)
Decree on Maximal Permissible Concentrations of the Radionuclides and Dangerous Goods in the Republic Water Flows, International Waters and Waters of the Coastal sea of Yugoslavia (SFRY 8/78)

5.3. Air protection regulations

Regulation on the first Measurements and Operational Monitoring of the Emission of the Materials into the Air from Fixed Sources of Emission and on Conditions for implementation (RS 70/96)
Directive on Noise in Nature and in the Living Environment (RS 70/95)
Directive on Limit, Warning and Critical Emissions of Material in the Air (RS 73/94)
Decree on Emissions from Stoves and Burners (RS /94)

5.4. Soil protection regulations

Decree on Limit, Warning and Critical Values of Dangerous Substances in Soil (RS 68/96)

6. LAWS REGULATING THE TECHNICAL AND FINANCIAL RESPONSIBILITIES FOR THE REMEDIATION OF URANIUM EXPLORATION, MINING AND PROCESSING FACILITIES

Act on the fund for the decommissioning of KRSKO nuclear power plant and dumping its radioactive waste (RS 75/94)

The law on permanent close-out of uranium ore exploitation and prevention of mining consequences at the Žirovski Vrh mine (RS 36/92) translated

MINING AND MILLING OF URANIUM ORE: INDIAN SCENARIO

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Abstract

The occurrence of uranium minerals in Singhbhum Thrust belt of Eastern India was known since 1937. In 1950, a team of geologists of the Atomic Minerals Division was assigned to closely examine this 160 km long belt. Since then, several occurrences of uranium have been found and a few of them have sufficient grade and tonnage for commercial exploitation. In 1967, the Government of India formed Uranium Corporation of India Ltd., under the administrative control of the Department of Atomic Energy, with the specific objective of mining and processing of uranium ore and produce uranium concentrates. At present the Corporation operates three underground uranium mines, one ore processing plant with expanded capacity, and two uranium recovery plants. Continuing investigations by the Atomic Mineral Division has discovered several new deposits and favourable areas. The most notable is the large Domiasiat deposit of the sandstone type found in the State of Meghalaya. This deposit is now being considered for commercial exploitation using the in-situ leaching technology.

1. INTRODUCTION

Soon after independence, the search to locate indigenous sources of uranium began as a sequel to the decision of Government of India to harness atomic energy for industrial purposes. It assumed greater importance with the rapid industrial development and limited availability of resources of fossil fuel and hydroelectricity in the country. Soon, it became imperative to locate uranium deposits in the country to meet the requirement indigenously. In the first decade of exploration, a number of areas showing anomalous concentration of uranium was identified all over the country specially in the states of Bihar, Rajasthan, Madhya Pradesh, Himachal Pradesh, Andhra Pradesh etc. (Fig. 1). Of all these locations, occurrences in the southern part of Bihar (Singhbhum Thrust Belt) were significant since they indicated the presence of uranium in mineable quantities.

The occurrence of uranium minerals in Singhbhum Thrust belt of Eastern India was known since 1937. In 1950, a team of geologists of Atomic Minerals Division was assigned the task of closely examining this 160 km long belt. Since then, several occurrences of uranium with sufficient concentration have been found out in this region and a few of them have already been taken up for commercial exploitation.

In 1967, Government of India formed Uranium Corporation of India Ltd. under the administrative control of Department of Atomic Energy with specific objective of mining and processing of uranium ore in the country to produce uranium concentrates. The Corporation started with one underground mine at Jaduguda in Singhbhum Thrust Belt of Bihar and a processing plant near the mine site. Later on, additional mining and milling facilities were created to meet the growing demand. The technology of uranium extraction is amply demonstrated by the working of the mill and mine at Jaduguda which has already completed three decades of uninterrupted production. As on today the country boasts with three underground uranium mines, one uranium processing plant with expanded capacity and two uranium recovery plants operating under the Corporation.

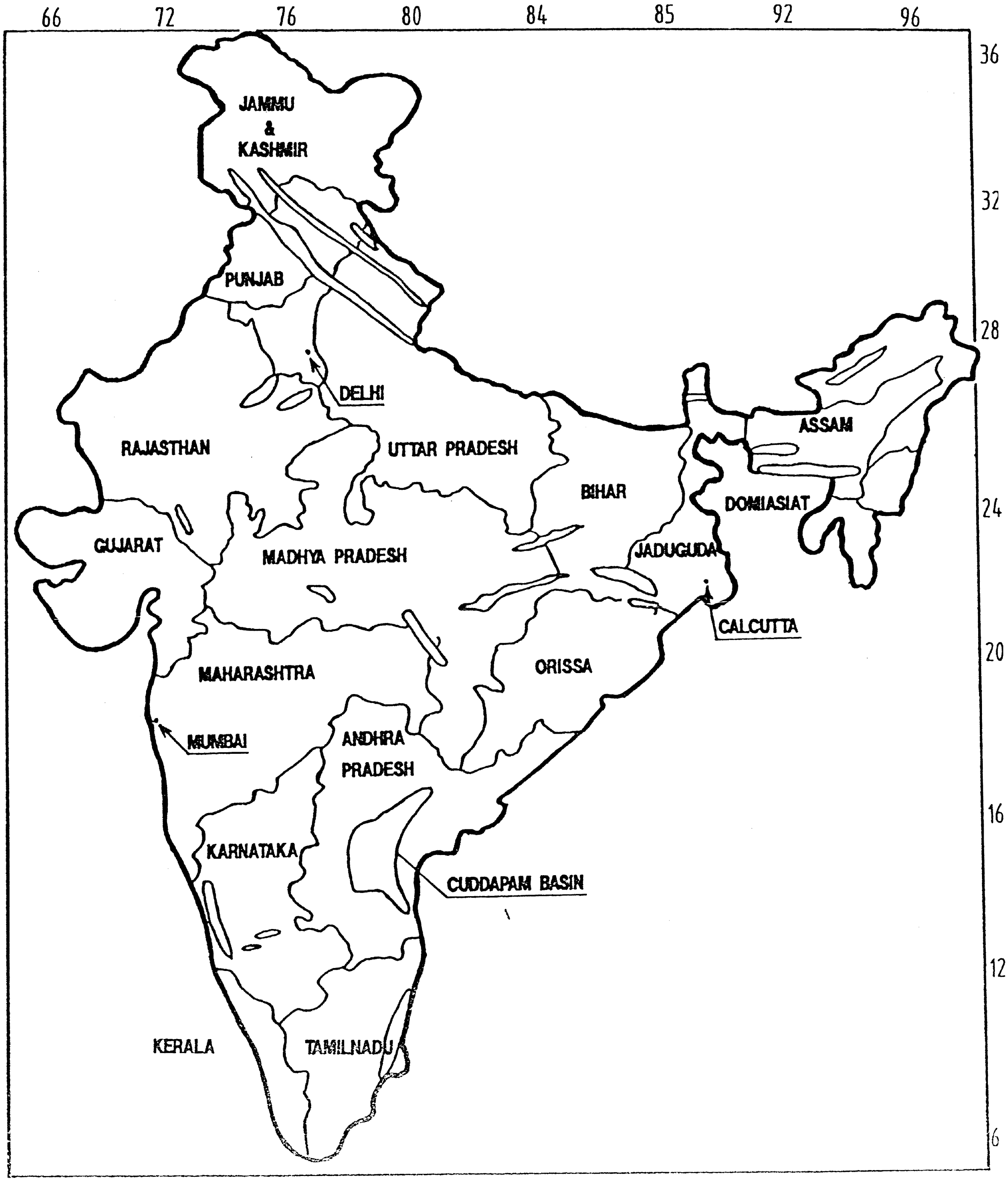

FIG. 1. Belts of uranium potential in India.

2. UNDERGROUND MINES

2.1. Jaduguda mine

Geologically, the deposit belongs to a zone of thrusting and shearing. The thrust belt is constituted by Archean metasediments. Older rocks (Chaibasa stage) have been thrust over the younger rocks (Dhanjori stage). The thrust contact is severely sheared and brecciated. Uranium occurs in this brecciated zone in a very finely disseminated form. The mineralisation

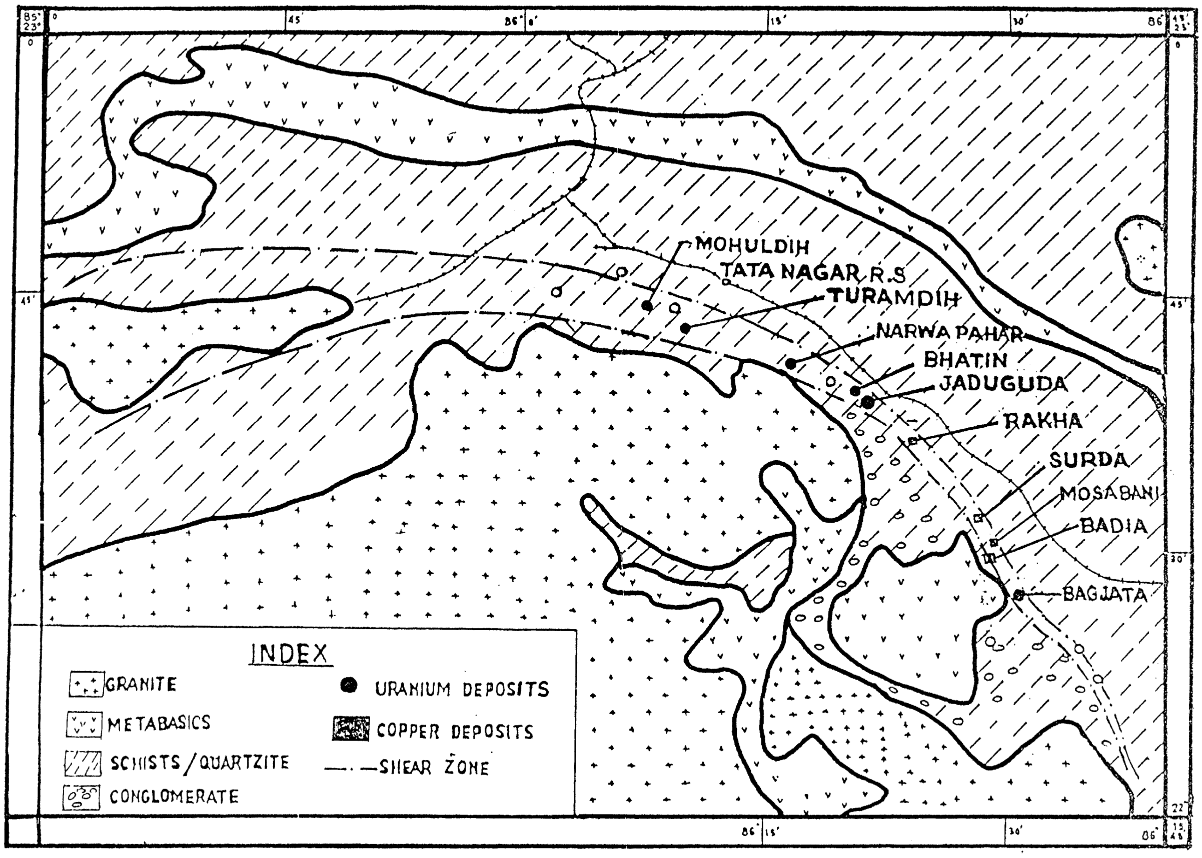

FIG. 2. Geological map of Singhbhum shear zone, showing uranium & copper deposits.

is structurally controlled and is confined to shears lying parallel to sub-parallel to the schistosity. The principal mineral of uranium is uraninite (Figs. 2 and 3).

The deposit has two lodes. The southern lode, known as the Foot-wall lode extends over a strike length of about 800 m from south-east to north-west. The northern lode, known as Hang-wall lode has a strike length of about 200 m and is noticeable only in the eastern sector. The ore shoot in the western sector of foot-wall lode is not only rich in uranium but also contains copper, nickel and molybdenum. The width of the orebody varies from 2 m to about 25 m with a moderate dip of about 40º.

Jaduguda mine is the first underground uranium mine in the country which is in continuous commercial operation for the last three decades. The deposit was discovered in April 1951. Detailed exploration by diamond drilling and initial exploratory mine development work was started soon followed by mine development work through adits and winzes. By the year 1964, mine had reached a depth of 100 metres below surface. Then a shaft was sunk up to a depth of 315 m along with the ore pass system, underground loading and crushing stations were made ready to produce 1000 tonnes of ore per day. The mine was deepened in second stage by deepening the shaft from 315 m to 640 m along with the production from the top levels. A novel method was used for the construction of this shaft. The main ore pass was sunk first and the shaft was raised from bottom to top. Instances of this method is very few and far in the world. The second stage shaft sinking was completed in 1977 and mining was commenced from deeper levels. The main shaft is completely lined with 5 m finished diametre and

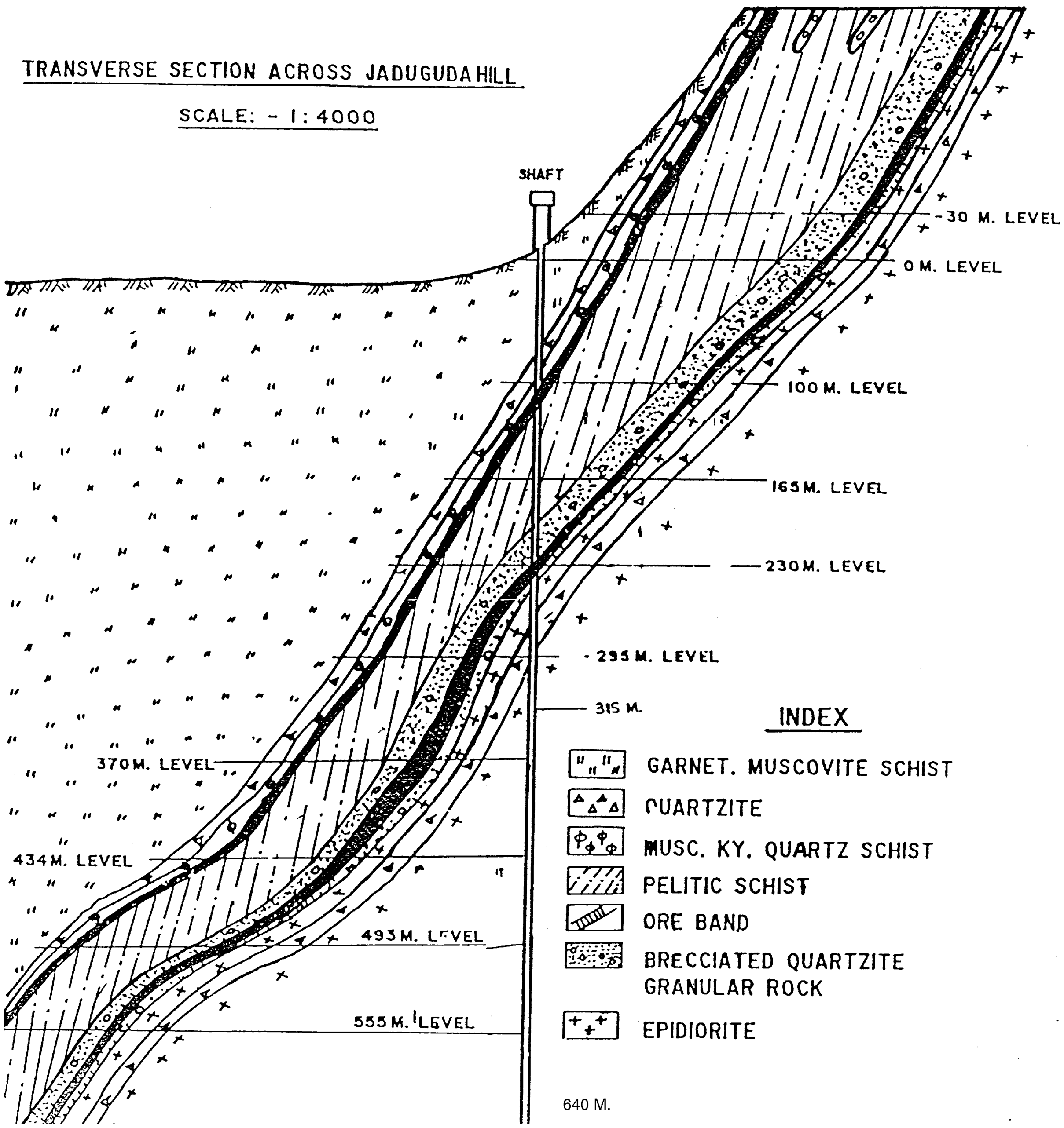

FIG. 3. Transverse section across Jaduguda hill.

equipped with two multi-rope friction winders, one for the cage and the other for the skip. The cage has two decks which is used for lowering men, material and hoisting of waste rock. The skip of 5 tonne capacity is used exclusively for hoisting of ore from 605 metre level (loading station). The winders are installed on an R.C.C. tower of 7.50 metres diametre at a height of 45 metres above the ground.

In the earlier stages, to boost production and to build up ore stocks shrinkage stopping was followed in the mine. Later on open timbered method of stopping was adopted. Presently the principal stopping method is the horizontal cut-and fill using deslimed mill tailings as the fill material. The levels are generally opened at 65 metres vertical interval and are connected to the ore drives. The ore produced from different levels in the mine are transferred to an ore-pass located near the main shaft. All the ore transferred from different levels are sized in an underground jaw crusher at 580 metre level. The crushed ore is stored in the ore pocket below the crushing station. The ore is finally hoisted to surface from 605 metre level loading station.

Shrinkage stopping adopted in upper levels during early stage of mining provided the opportunity for application of solution mining. Due to flat dip of the orebody, some ore was adhering to the footwall even after drawl from the chutes. Barren solution from the mill was sprinkled into the stops and re-circulated till values were built up. This water rich in uranium was then pumped to mill for uranium extraction. Considerable amount of uranium has been extracted by this novel method.

Jaduguda is a well designed mine with a nice functional layout not only for production but also for transportation and drainage system. It is the first underground metal mine in the country to be commissioned after independence. It is the first mine in the country to introduce a number of new techniques like using slip form method for shaft lining and construction of shaft headframe, use of trackless pneumatic loaders like LHD & CAVO, Alimak Raise climber for development of long raises, stope wagon for mechanized drifting, underground crusher etc. Presently, the mine is adopting better mechanisation for deeper levels by developing decline and ramp as an approach to stops and using electro-hydraulically operated twin-boom drill-jumbo, low-profile-dump-trucks etc. This upgrading of technology is expected to result in better stope productivity.

During last thirty years of mining, Jaduguda mine has gone to a depth of 555 m. Entire ore up to a depth of 434m has been exhausted. Present mining operations are confined to 495 m level and 555 m level. As the reserve depletes, continuous search and underground exploration has led to prove that the uranium bearing lodes of Jaduguda extends to a vertical depth of 750m and below. This has led to take a major decision to deepen the mine to 900 m by sinking an underground vertical shaft. This is referred as third stage of mine deepening (Fig. 4). With the find of the orebody and deepening of the mine, the life of the deposit is expected to increase by 20 years. The sinking work commenced in June 1992 and was completed in 1997. Shaft lining work is in full swing and will be ready for 3 commissioning soon. Orebody shows encouraging indications of continuity below 900m. In such an event, mine will be deepened further as fourth stage of operation after studying the feasibility.

2.2. Bhatin mine

It is a small, low grade deposit located at about 3 km west of Jaduguda in Singhbhum Thrust of Bihar state (Fig. 2). Uranium bearing outcrop on the top of the hill were traced at the initial stage of exploration. Subsequently, it was prospected by shallow and deep bore holes. Deep boreholes have indicated that the mineable orebody persists to a depth of 600 m.

The deposit is the western extension of Jaduguda orebody that has been displaced to the north due to a regional strike-slip fault (Tirukocha fault) in the post mineralisation stage. The geological settings, host rock and mineral characteristics are similar to Jaduguda deposit. The strike length of the deposit is about 400 metres having a dip angle of 35 to 45 degrees. The ore lenses occur in lenticular pattern. The average width of the ore-body varies between 2.50 m to 7 m. The deposit has a very high concentration of molybdenum which has been emplaced later to uranium minerilisation along some localised shear planes.

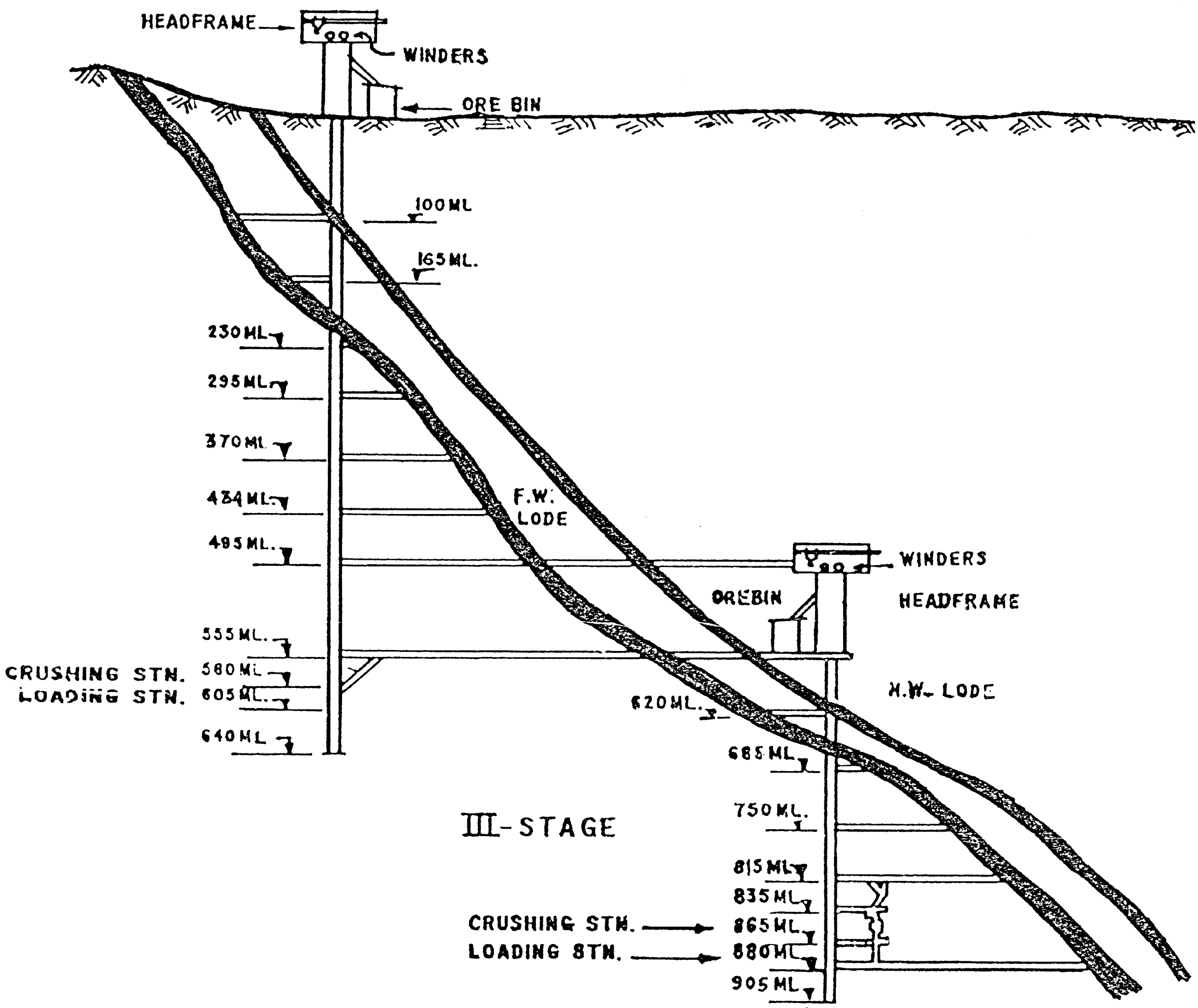

FIG. 4. III - Stage shaft sinking.

The proximity of this deposit to Jaduguda and the fact that its geological settings and ore mineral assemblages are similar to that of Jaduguda, made its commercial exploitation an attractive proposition. The mine construction work started in April 1983, and was commissioned in October 1986. The mine designing and construction work was carried out indigenously. The entry to the mine is through an adit driven at the ground elevation (second level). Two principal underground winzes have been sunk from this level to sixth level, a vertical depth of 135 metres below surface. The winzes are equipped with double drum electric hoists used for lowering of persons and hoisting of ore from the lower levels. A level has also been opened 25 m above the second level to win the ore above ground elevation. The capacity of the mine is to produce 250 tonnes of ore per day.

The principal stopping method followed is the horizontal cut-and-fill using deslimed mill tailings as backfill material. Stopping and transportation layout of the mine are similar to Jaduguda. Ore produced from Bhatin mine is transported to the processing plant at Jaduguda by dumpers and backfill material is obtained from there.

As the reserve in the upper level depletes, the mine is now being deepened to create additional production levels below 185 m. The existing winzes are being deepened up to a depth of 250 m and will be ready for use soon. Depending on the nature of mineralisation, subsequent deepening of the mine will be carried out either by sinking vertical shaft or by developing underground decline.

2.3. Narwapahar mine

It is located at about 12 kms north-west of Jaduguda (Fig. 2). Exploration of this deposit was carried out at a later stage. The deposit lies in the metasediments of Singhbhum Thrust Belt. The effect of regional thrusting in this zone appears very intense.

The metasedimentary sequence in Narwapahar deposit consists of a series of schistose rocks of varying composition. The uranium mineralisation is confined to the schistose units and is concentrated principally at a lithological boundary. The principal uranium mineral is uraninite which is finely disseminated throughout the host rock. There are a number of uranium bearing beds occurring as tabular lenticular horizons conformable with dip and strike of the schistosity. But six prominent bands are found mineable. At their maximum extend, the orebodies have a strike length of about 2 km and is known to persist to a depth of 600 m. The width of the orebody varies from 2 m to 7 m. Variations in thickness of each orebody exists along the strike as well as the dip. The dip of the orebody is about 30º.

The mining method adopted at Narwapahar mine is the most modern in the country Even very few mines in the world have perfected on this methodology. The entry to the mine is through a decline in the footwall of the orebody. Low gradient ramps are developed as entry to the stop. This has helped in using large trackless mining equipment like twin boom drill jumbo, low-profile-dump-truck, service truck, passenger carrier, low-profile road grader, scissor lift etc. Provision of ramp in stope has helped in moving machinaries from one level to another. The method has brought in early commissioning of the mine for production, low cost and high productivity. Such technology has allowed interchanges between different stoping methods that becomes necessary due to the wide variations in thickness and differing configurations of the orebody.

Presently, the decline has been developed to a depth of 140 m and four levels at intervals of 35 m below surface are under production stage. Three different stoping methods are adopted in Narwapahar Mine. For orebody width up to 2.5 m, inclined room-and-pillar method is followed. Step mining method is followed for thickness ranging between 2.5 m to 7 m, and for thickness above 7 m Post Pillar method is followed. The voids in the stopes are filled with deslimed mill tailings. The long term as well as short term stability of the surface is ensured after analysing all the above methods of extraction technique by means of numerical modelling using BEFE software. Any modifications to the design layout of the mine is first tested for stability point of view before adopting them in practice.

A vertical lined shaft of 5 m finished diameter has already been sunk up to a depth of 355 m which will serve as an entry to deeper levels. Shaft equipping work is in progress. Narwapahar mine shaft will have two ground mounted friction winders - one for the cage winder and the other for skip. The general arrangement in this shaft will be similar to the main shaft of Jaduguda mine like ore-pass system, underground crusher and loading station etc. After the commissioning of the main shaft, it will be connected to the mine and ore from lower levels of the mine will be hoisted to surface through skip.

Narwapahar mine is designed to produce 1000 tonnes ore per day. All the ore from Narwapahar mine is transported to Jaduguda mill for processing and backfill material is taken from mill to the mine site.

3. PROCESSING PLANT

Processing of ore is an integral part of the mining. The ore extracted from Jaduguda mine is being processed at Jaduguda mill which was made ready a little after the commissioning of the mine.

The ore from Jaduguda is transported by conveyor belt to crushing section in two stages. This is followed by two stage wet grinding with primary rod mill and secondary pebble mill. The ground ore in the form slurry is then pumped to by-product recovery plant for the recovery of copper, nickel and molybdenum sulphide as concentrates using flotation technique. The slurry after flotation is thickened, filtered, repulped and pumped for leaching in pachucas which are essentially air agitated tanks. During the process of leaching, tetravalent form of uranium is oxidised to hexavalent form which is soluble in acidic medium. For this sulphuric acid and pyrolusite are added to maintain pH. Temperature is maintained between 36ºC to 38ºC. The pachucas are kept in line. The slurry overflows from one pachuca to another and after twelve hours of retaining when the slurry comes out of the last pachucas, around 95% of uranium get leached out. The leached slurry is filtered in two stages employing string discharge vacuum drum filters. Primary filtrate is clarified on filter aid coated pre-coat filters and sent to purification and concentration. Secondary filtrate is sent to disc filter for repulping ore cake.

The liquor at this stage contains 0.4 - 0.6 gm/1 of U_30_8 ferrous and ferric sulphates, dissolved manganese, sulphate ions and other impurities. This is concentrated and purified by ion exchange process. Two columns-system with strong base ion exchange resin is used. The liquor is passed through both the columns. Once U_30_8 from second column is found 0.005 gm/1 the first column is cut off and eluated with normal acidified salt solution. The strong eluate so produced contains around 4-5 gm/1 U_30_8 ferric ions etc. This liquor is neutralised with lime to pH 3.9 whereby ferric ions gets precipitated. This is thickened and filtered. As along with iron some of the complexes of uranium also gets precipitated, it is sent back to leaching to recover the precipitated uranium. The clear liquor from thickener is neutralised further to pH 7 by magnesia whereby uranium gets precipitated as magnesium-di-uranate or yellow cake. This is thickened, filtered, dried and packed in drums. U_30_8 content in yellow cake is about 74%. The yellow cake is sent to Nuclear Fuel Complex for further processing for conversion into nuclear fuel grade.

The mill at Jaduguda is under continuous operation since its inception in 1968. With the commissioning of Bhatin mine in 1986, the capacity of the mill was expanded in 1987 to 1370 tonnes per day. Further expansion of the mill was undertaken in 1995 to treat the additional ore produced from Narwapahar mine. The fully automated expanded mill has been commissioned recently treating 2090 tonnes of ore per day. The new plant is now equipped with some of the state-of-the-art process control system like Distributed Control System,. PLC's and on-line XRF based uranium analyser to monitor and bring out efficiency in recovery.

4. URANIUM RECOVERY PLANTS

Adjacent to uranium mines in Singhbhum Thrust Belt of Bihar, a few large underground copper mines are under operation. These copper ore contain small amount of uranium minerals which can be recovered as by-products and they have become the auxiliary source of uranium in the country. Two such recovery plants at Rakha and Moosabani are set up near the copper concentrators in the region. After the extraction of copper, tailings are sent to these plants for recovery of uranium. Though the uranium content is very negligible in these tailings, the enormous volume available makes the uranium recovery process very attractive. The copper tailings are subjected to gravity separation using Wilfley tables. High specific gravity particles get concentrated at the bottom of the flowing film. The grade of uranium in mineral concentrates during the process goes up by 4 to 7 times. These uranium mineral concentrates are transported to Jaduguda mill by road for further processing. Efforts in this regard has not only generated an appreciable amount of uranium for the country, but has also gone a long way in minimising the radiation and pollution hazards from the waste streams of copper concentrators.

5. NEW DEPOSITS

Investigations and exploration carried out by Atomic Minerals Division through out the country has established many new mineable reserves and potential areas of which mention may be made of Turamdih, Mahuldih, Bagjata of Singhbhum Thrust Belt in Bihar, Bodal-Bhandaritola in the state of Madhya Pradesh, Lambapur in Andhra Pradesh, Shiwalik formations in the foot hills of the Himalayas etc. However, the greatest and the most noteworthy discovery of this decade is the large sandstone type deposit in the upper Cretaceous-Tertiary sedimentary basin at Domiasiat in the state of Meghalaya. With the increasing demand of uranium to meet the fuel requirements for country's nuclear power programme, the deposit is now being considered for commercial exploitation.

5.1. Domiasiat uranium project

The deposit is located in the southern slopes of Meghalaya plateau in West Khasi Hills of Meghalaya. A detail study of geology and genetic evolution of the Domiasiat uranium deposit has also opened up large areas for discovering similar deposits elsewhere in Meghalaya plateau.

Domiasiat deposit is the first of its kind in the country to be found in the sedimentary basin. The basement of this basin is intruded by Pre-Cambrian rocks. Uranium mineralisation is associated with grey, fine to medium grained sediments. These sediments directly overlie the basement granites (Fig. 5). Mineralised bands are confined within 45 m depth from the surface. They are fairly flat with general dip of 5 to 10 degrees. Thickness ranges from 1.5 m to 29.6 m averaging 3.57 m. A few more deposits with similar geological features have also been discovered in Domiasiat plateau and are in advanced stage of exploration.

Analysis of geology of Domiasiat uranium deposit with respect to its formation history and technical properties show its amenability to in-situ leaching technology.

The technique of in-situ leaching, is a relatively unknown method in India, though it is largely practised and successfully implemented in many countries of the world. Extraction in this method is accomplished through the dissolution of natural in-place uranium in underground and recovery of the leached solution from underground for further processing. Suitable solvent liquid is sent into the ore body through the injection wells, the liquid is allowed to pass through the orebody for desired period so as to dissolve the metal and finally the pregnant liquor is recovered through production wells. Monitor wells are also installed to regulate the excursion of liquid beyond the mining environment.

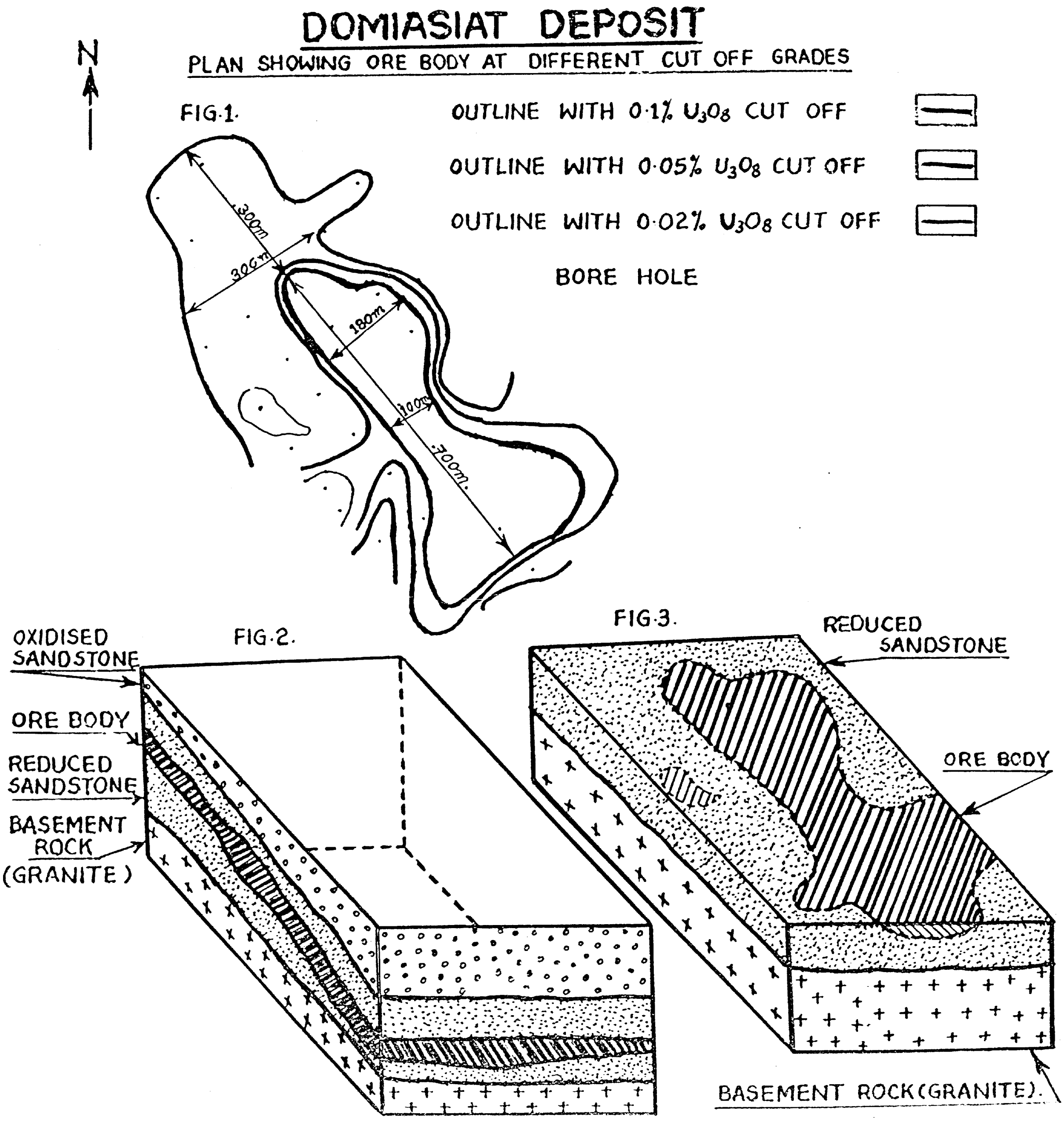

FIG. 5. Domiasiat deposit.

There are many advantages of adopting In-situ Leaching technique in Domiasiat over other conventional methods like open-pit or underground mining.

(A) Unlike in conventional mining and processing, following operations will not be required.

- (a) overburden removal
- (b) drilling/blasting in overburden and ore
- (c) surface transport of broken rock
- (d) maintenance of roads required for transportation
- (e) crushing & grinding of ore
- (f) tailings disposal system.

(B) Better economic indices of the deposit because of
  (a) Lower capital cost
  (b) Less manpower
  (c) FEgh productivity
  (d) Quicker return on investment.

(C) Environmental damage to the mine site will be considerably reduced because
  (a) Surface disturbance/infrastructure is minimised.
  (b) Large quantities of rock/tailings are not to be disposed of
  (c) Radium which is a major source of radiation will be left in the host rock.

(D) Less requirement of land will make land acquisition and subsequent re-cultivation possible.

(E) Unfavourable geology like incompetent host rock, poor ground conditions, water in-flows etc. will act to the benefit of the method.

(F) Continuous operation throughout the year will be possible inspire of unfavourable climatic conditions.

(G) Early production from the deposit can be achieved.

(H) Nearby, small, poor/low-grade deposits can be opened with minimum investment on infrastructure.

Presently, some more technical information specially related to the geo-hydrological properties of the deposit are being generated. Field tests with wide complex investigations for choosing the optimal ISL technology for the project are being planned. These tests will include well drilling, recovery and restoration of aquifer which may offer a model project for its application in other deposits also.

6. CONCLUSION

India is one of the few countries in the world where the entire gamut of nuclear fuel cycle is well developed entirely by an indigenous effort. There is a steady growth in installed capacity of the nuclear power plants during fast few years and this has necessitated a comparative growth of uranium mining and milling capacities. The known reserves are sufficient for the planned growth but there is a need for stepping up of exploration and identifying additional resources. Unfortunately, the country is not blessed with any rich grade uranium deposit. Deposits which would have been easier to discover have almost all been found out so that the future exploration demands greater ingenuity and skill based on sophisticated technique and advanced research out-put. The technology of uranium mining and processing though has been amply demonstrated, still the efforts are on to bring new deposits into production as early as possible, to reduce the cost of production, to improve upon the recoveries in processing and improving the recovery from copper tailings etc. The thrust areas are now well defined and prioritised to meet the requirement with alacrity and ability.

Radiation exposure during mining & milling operations

Average Annual Dose to Mine workers during 1997.

Jaduguda mine	:	7.19 mSv	Against Annual limit of 20 mSv
Bhatin mine	:	7.48 mSv	
Narwapahar mine	:	6.40 mSv	

Average annual dose to mill workers during 1997 was 2.88 mSv against the limit of 20 mSv.

Average radiation & radioactivity levels

Location	Av. Gama radiation μGy L^{-1}	Av. Rn. concentration Bq m^{-3}, EER	Long lived radioactive dust Bq.m^{-3}	MDV Dust Av. Bq.m^{-3}
Jaduguda mines	2.65	460	0.04	---
Bhatin mine	2.80	440	0.01	---
Narwapahar mine	1.80	410	0.02	---
Jaduguda mill	2.84	--	0.03	1.29
Derived limit	8.0	1000	0.06	4.50

Public Exposure: 0.43 mSv/y above local natural Background (limit: 1 mSv/y)

Average Gamma Radiation Dose in Public Domain: 1.35 mSv/y
Local Natural background: 0.92 mSv/y

0.43 mSv/y

URANIUM MINING AND HEAP LEACHING IN INDIA AND RELATED SAFETY MEASURES — A CASE STUDY OF JAJAWAL MINES

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Abstract

Exploration and exploitation of uranium involves drilling, mining, milling and extraction processes including heap leaching in some cases. At the exploration stage, the country's laws related to statutory environmental clearance covering forest and sanctuaries or Coastal Regulatory Zones (CRZ) are equally applicable for atomic minerals. At the developmental mining or commercial exploitation stage in addition to the environmental impact assessment, the provisions of Atomic Energy (working of Mines, Minerals and handling of Prescribed Substances) Rules 1984 are also to be followed which covers radiation monitoring, pollution control and other safety measures which are enforced by licensing authorities and the Atomic Energy Regulatory Board (AERB) of India. In India, Jaduguda, Bhatin, Narwapahar in Singhbhum Thrust Belt (STB), Asthota and Khiya in Siwaliks, Domiasiat in Cretaceous sandstones, Bodal and Jajawal in Precambrian crystallines, are some of the centres, where mining has been carried out up to various underground levels. Substantial amount of dust and radon gas are generated during mining and milling operations. Though uranium mining is considered as hazardous for contamination by radionuclides, it is observed that many non-uranium mines have registered up to 100 mWL radon concentration, e.g. copper mines in STB area show up to 900 mewl in a few cases. Compared to this the Uranium mines in India have not shown any increase over the limits prescribed by AERB. Specific problems associated with mining include release of radon and other radioactive pollutants like Th-230, Ra-226, Pb-210 and Po-210, substantial dust generation, ground water contamination, proximity of population to working mines and environmental surveillance. These problems are adequately handled by periodical monitoring of various radiological parameters such as radon daughter working level, long lived alpha activity and concentration of radionuclides in gaseous, liquid and solid medium. Pre-project and post-operational data collections both in the project areas and in the surrounding drainage systems are mandatory and overviewed by AERB before clearance. In Jajawal underground mines in Central India, the radiation level is registered at 0.12-0.25 mR/hr and radon daughter working level is measures at 0.005 to 0.015 WL for air. These levels have shown an increase of 15 to 20% during the operations. About 1000 tonnes of low grade ore was heap leached on the surface as technology demonstration project. Measurements of water in pre-heap leaching stage, have indicated concentrations of different nuclides at 0.90 mg/cu.m. (U Nat.), 35 bq/cu.m. (Ra-226), 33 bq/cu.m. (Th-230) and <2 bq/cu.m. (Po-210). Long lived alpha activity in and around heap leaching site has been measured at 0.13 to 0.38 bq/cu.m during the process of operation. Post operational biological uptake of radionuclides, viz. U (natural) : 0.057 mg/kg; Ra-226 : 1.69 Bq/kg; Th-230 : 5.13 Bq/kg and Po-210 : 2.98 Bq/kg, show an increase of 20 to 30% above the pre-operational measurements. The radionuclide related pollution could be contained to manageable limits by current strategy of ventilation of underground mines, disposal by isolation and burial of waste, use of wet scrubbers, adding neutralizing agents to tailing liquids, besides following the principle of ALARA.

1. INTRODUCTION

Uranium deposits in India are known in several geological settings and amongst them, vein type, sandstone type and unconformity-related, are the most important. The deposits of low to medium grade (0.03-0.1%) and moderate to low tonnage are known to occur in different geological periods commencing from Lower Proterozoic to Middle Miocene as at Jaduguda, Bhatin, Narwapahar in the Proterozoic Singhbhum Thrust Belt (STB), Bodal and Jajawal in Precambrian crystallines, Asthota and Khiya in the Miocene Siwalik sandstones, Domiasiat in Cretaceous sandstones. Uranium mining has been carried out up to different stages such as exploratory and production at different places. Production mining of uranium ore at present is essentially confined to some deposits of Singhbhum Trust Belt (STB), namely Jaduguda, Bhatin and Narwapahar. Besides, the uranium mining, heap leaching operations and milling have also been carried at certain places.

The successive stages of exploration leading up to the final exploitation of uranium ores, require stringent implementation of different statutory clearances and adherence to such regulations has been an endeavour of utmost importance both by Government Agencies as well as by Non-Governmental Organizations. Atomic minerals industry is also governed by the country's laws related to statutory environmental clearance covering forests and sanctuaries or Coastal Regulatory Zones. Developmental/exploratory mining and commercial mining are governed by the provisions of Atomic Energy Rules, 1984 (AER), besides the stipulation of environmental impact assessment as applied under Environmental Protection Act, 1986 (EPA). EPA mandates for the preparation of the Environmental Management Plan (EMP) to satisfy the statutory provisions of the Ministry of Environment and Forest. AER stipulates radiation monitoring, pollution control and other safety measures which are enforced by licensing authorities and Atomic Energy Regulatory Board (AERB) of India.

2. SAFETY PROBLEMS IN URANIUM MINES

Uranium mining besides affecting radiation levels and dust levels, also influences the environment in several ways such as noise pollution, air pollution, degradation of land and environment by contamination of ground water, surface water and soil. Atomic Minerals Division (AMD) has undertaken the task of generating baseline data on all the projects for better environmental management. Specific problems associated with uranium mining include release of radon and other hazardous radioactive pollutants, besides those mentioned above. These problems are adequately handled by periodic monitoring of various radiological parameters such as radon daughter working level, long-lived alpha activity and concentration of radio-nuclides in gaseous, liquid and solid medium. These safety measures are enforced by AERB through constant monitoring during different stages of mining and milling operations.

Radium present in the ore is the major source of radon in mines. Radon produced by the decay of radium located in the ore matrix moves out by recoil into pore spaces. This locked up radon is released during fresh blasting. With relatively long half-life of radon, the decay products seldom reach secular equilibrium with radon. Thus the decaying radionuclides attach to available surfaces and form radioactive aerosols. The radon produced by the decay of radium and radon progeny available as radioactive aerosoles are major pollutants. Thus removal of these aerosols is an important factor to reduce the health hazard for occupational workers. This depends on mine layout, ventilation system, concentrations of condensation-nuclei, aerosol and dust as also on the available exposed mine surfaces. These are best achieved by proper ventilation, sprinkling of water in the mines along exposed mine surfaces and closures of unused mine sections. The above measures undertaken in uranium mining industry have helped in containing the level of radon in mines. Data of some mines is presented in Table I.

3. RADIOLOGICAL PARAMETERS FOR NON-URANIUM MINES

Compared to uranium mines, measurements undertaken in some non-uranium mines in India have brought out an interesting study. The survey was conducted in major mineral mines from various parts of India [1]. The coal sector has indicated very low radon levels, mostly below 10 mWL. The underground metalliferous mines, in general, have enhanced levels of radon activity ranging from 10 to 100 mWL. In many copper mines, the air activity levels were considerably high, ranging from 100 to 300 mWL. Except for one mine each of lead & zinc, gold and mica, all the mines that exceeded 30 mWL, were copper mines (Table II). In one mine, the radon level was as high as 900 mWL.

TABLE I. GROSS RADIATION, RADON AND ITS DAUGHTERS IN AIR AND WATER AROUND SOME UNDERGROUND URANIUM MINES IN INDIA [MODIFIED AFTER 3].

Sl. No.	Area/Deposit	External radiation in mines (uSv/hr)	Annual Dose in mines (uSv/yr)	Water
1.	Jaduguda mine, Bihar	----	----	Seepage water from uranium mill U (mg/l) Ra-226 (pCi/l) 0.52 to 3.29 0.82-2.56
2.	Jajawal mine, Madhya Pradesh	0.3-1.5	1.6 (External) 6.1 (Internal) *7.7 (Total) (60)*	Radon dissolved in water (kBq/cu.m) Mine water 3.8 Well water 1.15 Stream 2.00
3.	Bodal mines, Madhya Pradesh	1-1.6	13.0 (External) 6.8 (Internal) *19.8 (30)*	Radon dissolved in water (kBq/cu.m) Mine water 1.7 Well water 0.5 Tube well 1.9 – 4.7
4.	Astotha mine, Himachal Pradesh	0.2-2.5	1.40 (External) 3.00 (Internal) -------------------- *4.40 (30)*	Radon dissolved in water ---- Spring 0.7 Stream 0.5

TABLE II. RADON LEVEL-WISE CLASSIFICATION OF NON-URANIUM UNDERGROUND MINES IN INDIA [1]

S.No.	Average Radon Level (in WL)	No. of Mines Mineral wise
1.	<10	Coal – 9, Gold – 3, Manganese – 2, Mica – 4
2.	10 – 30	Lead & Zinc – 2, Barites – 2, Mica – 2, Manganese – 1
3.	30 – 1000	Lead & Zinc – 1, Copper – 4, Gold – 1, Mica – 1
4.	100 – 300	Copper – 3
5.	>300 (900 m WL)	Copper – 1
		Total = 36 Mines

Percaput and collective dose equivalent of 80 mSv/Y and 16 person Sv/Y can be calculated with an occupancy factory of 0.75 and 2000 working hours per year for an activity level of 900 mWL. Compared to this, the Jaduguda Uranium mine has given percaput and collective dose equivalent values of 26 mSv/y and 28 person Sv/y, respectively. These observations clearly indicate that Indian uranium mining industry has been adhering to the mandatory stipulations enforced by AERB and ICRP [2] by maintaining optimum level of ventilation.

4. SAFETY PARAMETERS IN URANIUM DEPOSITS IN INDIA

Singhbhum Thrust Belt (STB) in Bihar State is a major uranium province. Uranium mining at Jaduguda, Bhatin and Narwapahar and milling at Jaduguda have been in progress for the last many years. The ground level exposure rates vary in the range of 0.4 to 46 uR/hr which are below the maximum permissible limit approved by International Commission on Radiological Protection [2].

Sandstones of Upper Cretaceous period host uranium mineralisation at Domiasiat, Meghalaya State with near surface manifestation of flat and tabular shaped body [3]. Exploration has been carried out in this area. The background radiation levels in the surroundings of the area, range from 4 to 12 uR/hr and rise up to 200 uR/hr near the exposures of ore body. In general, the surface radiation levels measured in the area are much lower than 1000 uR/hr, the derived limit for radiation exposure level considered for 2000 hour/year for occupational workers [4].

Besides these areas, exploratory mining has been carried out in several other areas, some of which are Asthota and Khiya, in Himachal Pradesh and Bodal in Madhya Pradesh. The surface radiation exposures in these areas have been within the limits enforced by AERB. The details concerning these areas are presented in Table I.

5. SAFETY MEASURES IN MINES AND HEAP LEACHING PLANT IN JAJAWAL AREA

Uranium mineralisation in Jajawal area, District Surguja, Madhya Pradesh (Fig. 1) is associated with hard and compact quartzo-feldspathic cataclasite and moderately hard quartz-chlorite-biotite schist. Uranium mainly occurs as dissemination in the form of pitchblende and coffinite associated with iron oxide. The Jajawal uranium deposit was taken up to test the feasibility of extraction of uranium, before full fledged commercial exploitation by mining and milling. Exploratory mining was therefore taken up by development of underground levels. Heap leaching was also initiated on the stacked ore. The project aimed at technological demonstration to recover uranium by bulk ore heap leaching near the mine site.

The uranium ore generated as a result of exploratory mining was treated on a pilot plant scale for the recovery of uranium. Thus heap-stack of 1000 tonnes of ore was subjected to heap leaching with an objective to establish technological, environmental and economic parameters for treatment and handling of low grade and small tonnage ore deposits located in remote areas where establishing commercial mining and milling facility may not be viable. The heap leaching plant was established in the proximity of mines area. While treating the ore for heap leaching, no crushing of ore was undertaken and run-off-mine containing about 5% finer particles of 105 micron or less size was treated directly. In this way, hazards arising out of fine dust in environment and subsequent disposal of large quantity of silt size tailings, have been avoided.

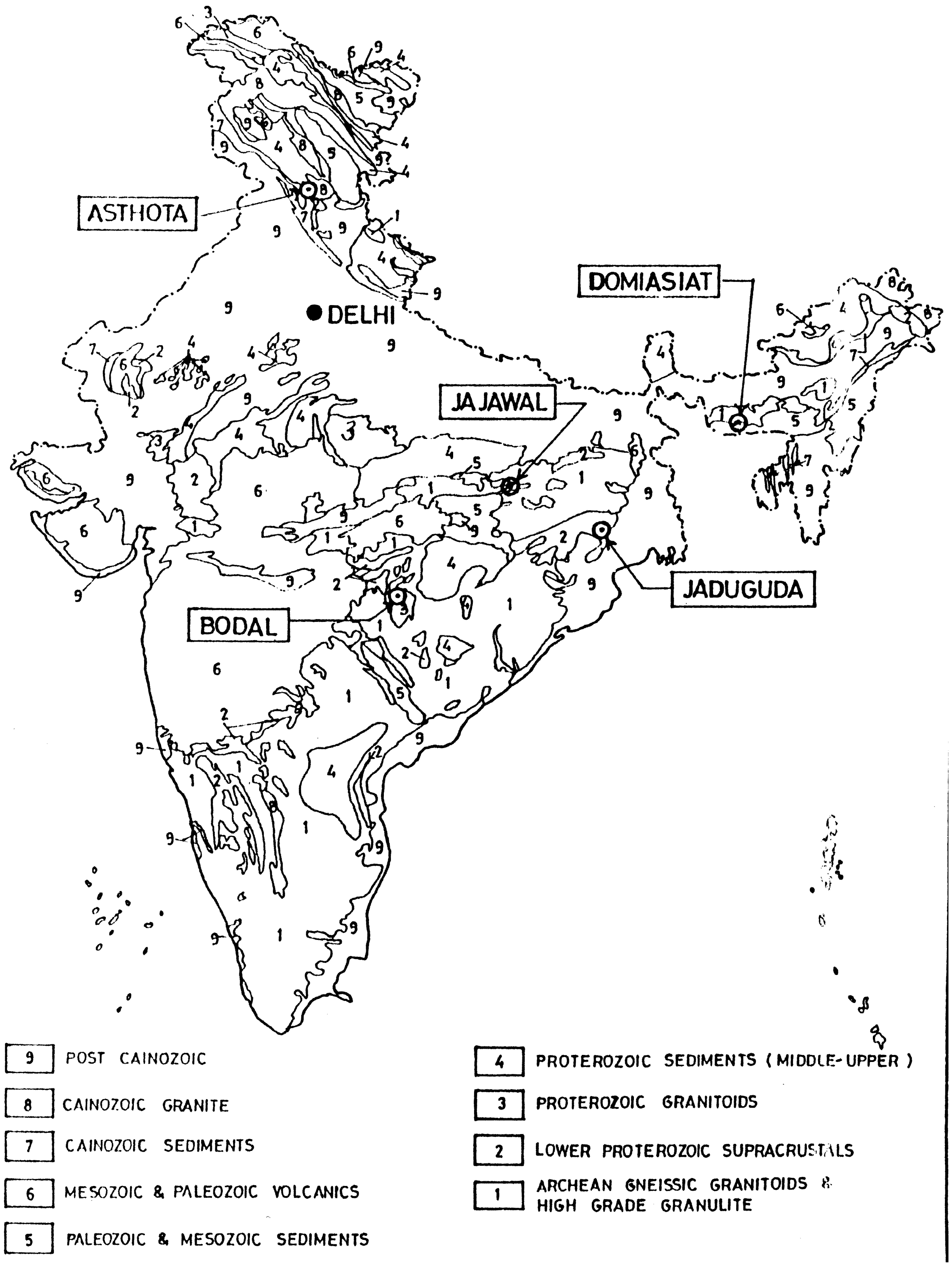

FIG.1. Geological map of India showing location of uranium mines.

6. MEASURES IN UNDERGROUND MINE

The hazards due to airborne radiation result from the inhalation of radon, its daughters and from long-lived alpha emitters present in the mine atmosphere in the form of dust. The radon progeny accumulate at a very fast speed due to their short half-lives. In order to contain the build up of short lived daughters, optimum level of ventilation is required to be maintained [5]. Statutory ventilation requirements demand mine air circulation containing >19% oxygen and <0.5% carbondioxide. It has been observed that air required to control heat, dust and diesel emission is sufficient to remove radon and its daughters.

As per the provisions of ventilation regulations, air requirement is 0.09 to 0.1 cu.m./second/tonne of rock broken per day. In order to contain the radon related hazards, the intake airways are located outside the ore zones, circulation of air through stopes/working faces in series is avoided, long period residence of broken ore at underground locations is avoided, mined out or abandoned parts of mines are sealed to prevent avoidable contamination and drainage water is kept out of intake airways and working places [7]. The ventilation measurement in different parts of mines are given in Table III.

External radiation in the form of beta and gamma emitted from the ore are generally high near the ore body (Table IV). However, the radiation level is generally less than 1 mR/hr. In the area surrounding the mine and heap leaching plant, the gamma radiation level vary from 0.016 to 0.055 mR/hr (Fig. 2).

TABLE III. VENTILATION MEASUREMENT IN JAJAWAL MINES [MODIFIED AFTER 6]

Location	Air Velocity m/h	Cross Section sq.m.	Quantity of air cu.m/min
Adit-I Xcut	7.0	5.175	1071.20
W-75 winze	158.6	4.84	767.60
Underground drill site in drive	345	0.159	54.80
Adit-2 exhaust Ventilation Shaft	228	5.05	1151.40

TABLE IV. RADIATION LEVEL IN JAJAWAL MINE [MODIFIED AFTER 6]

Location	Radiation Level, uR/hr
Adit-I mouth	18-22
Cross Cut Adit I	20-40
E-17 Station	40-50
Winze – 75	100-200
Underground drill site	40-50
Over ore dump	200-500
Over waste dump	75-80
Adit-II near Ventilation Station	200-300
2 km west of mine area	10-18

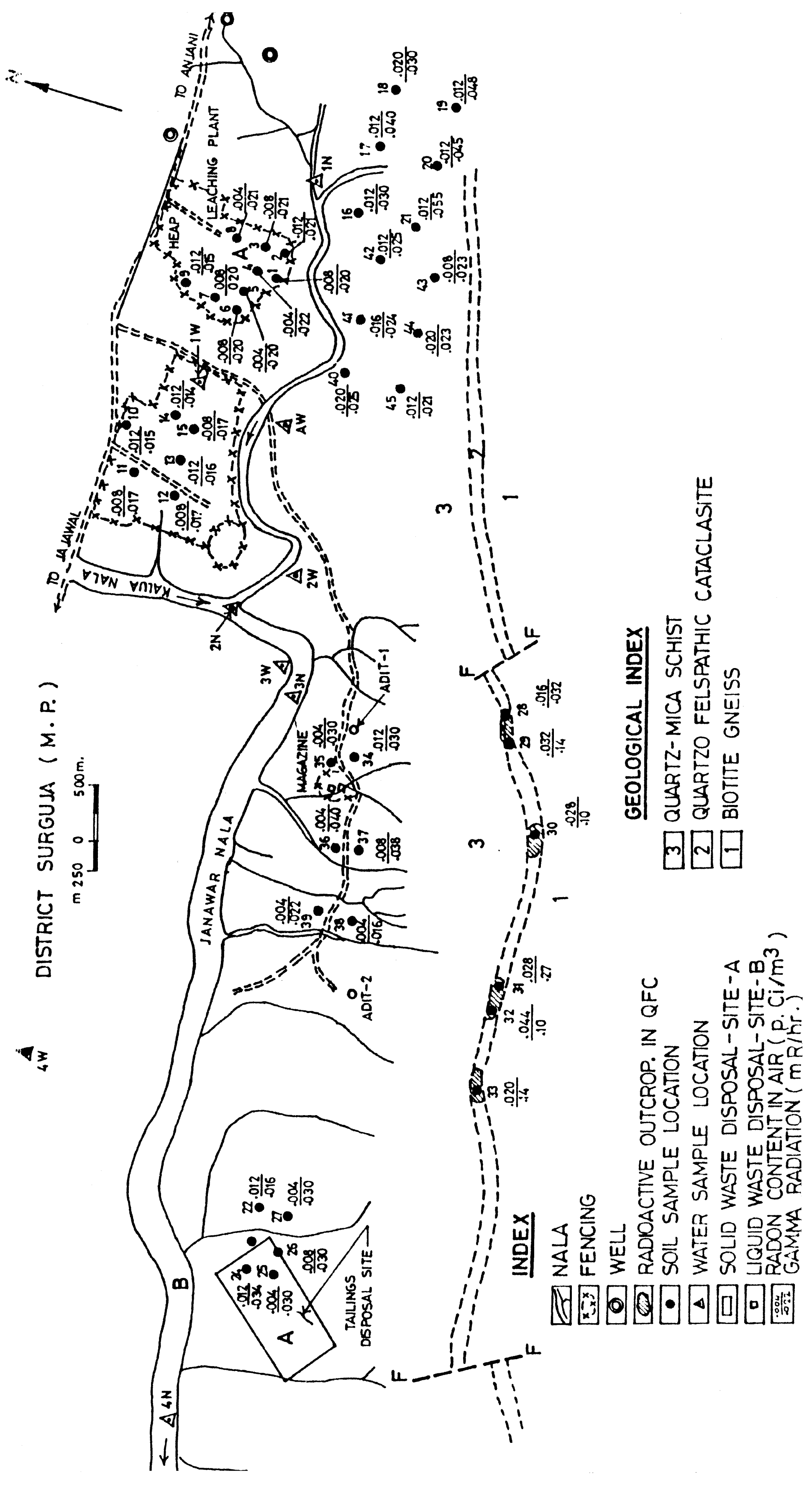

FIG. 2. Site plan of Jajawal mine and heap leaching unit (showing radiation levels).

7. MEASURES IN HEAP LEACHING PLANT

Heap leaching was carried out on a 1.5 m high heap loaded on a bitumen coated pad. Non-metallic wiggler type sprinklers were used to sprinkle the lixiviant evenly on the stack. Manganese dioxide was used as an oxidant and sulphuric acid was used as leachant. The process consisted of sprinkling of acidified water on the ore stack, selective adsorption on the ion exchange resin, elution and precipitation of eluates for uranium recovery [8]. Agitators and Nutsche filters were used for effective agitation and filtration of sodium diurnate slurry. In order to contain hazardous effects, high importance was given to constant environmental monitoring by analysis of air, water and soil samples. Seepage monitoring wells were made around the heap leaching plant. The production of liquid effluents was minimized by adopting zero discharge technique [8]. The solid and liquid effluents were treated separately to bring down the concentration of radionuclides to within the prescribed limits for discharge.

The filtrate after removal of yellow cake, was treated with barium chloride and the barium-radium sulphate was stored in the abandoned part of the mines. The effluent, so generated, was re-acidified to 7-8 pH and discharged after dilution to levels within prescribed limits [5, 9]. The analysis of effluent discharge is given in Table V. After neutralization, the tailings containing low concentration of radio-nuclides (Table VI) were mixed with lime and buried in trench with embankments. The tailings were covered by 30 cm thick soil and thoroughly compacted to ensure that material has low water permeability [5]. Post burial monitoring wells were made around the disposal site for environmental monitoring. Alternatively, abandoned parts of mines are also available for dumping of waste in future.

In order to monitor the environmental impact of the heap leaching operation, radiation surveys were undertaken around the heap leaching plant at pre-operational stage as well as during and post operational stage. The monitoring involved measurement of (1) gamma-radiation level (2) radon daughter working levels (3) long lived alpha activity (4) radionuclides in stream and well water samples and (5) radionuclides in soil samples in and around the heap leaching plant. Besides this personal dosimeter devises (TLD) were provided to occupational workers to monitor external dose [7, 10].

Pre-operational gamma radiation levels around heap leaching plant vary from 7 to 20 uR/hr. However, these levels have shown an increase up to 24 uR/hr in the post operation stage (Table VII) in the surroundings of plant and up to 87 uR/hr within the plant area. In leaching site these values show variations. Radon daughter working level concentration and long lived alpha activity show an increase from 10 to 50% in the post operational measurements (Table VIII). Distribution of radionuclides in water and soil samples around heap leaching plant have registered marginal variation (Tables IX and X). Plants growing abundantly around heap leaching site, were analyzed at pre- operational and post-operational stage, for radionuclides. Papaya Indica near the leaching site has shown increase in radium content (Table XI).

8. SUMMARY AND CONCLUSIONS

Exploratory mining for uranium and heap leaching in Jajawal area has given a new insight for the technological feasibility for extraction of uranium without bringing radiological damage to environment. Gamma radiation levels in and around Jajawal are in the range of 10 to 87 uR/hr, and higher near the ore body and working places (250 uR/hr). Even in areas where rich ore grade is expected it is possible to restrict hazards by controlled exposure and use of personal dosimeters. Water samples from the streams and wells near the plant as well as in the

TABLE V. ANALYSIS OF DISCHARGED EFFLUENTS FROM HEAP LEACHING PLANT AT JAJAWAL

S.No.	Component	Quantity
1.	pH	7.3
2.	U	<1 ppb
3.	Mn	<0.1 ppm
4.	Fe	<0.2 ppm
5.	SO4	65 ppm
6.	Cl	45 mg/litre
7.	Conductance	1.3 mmhos
8.	Na	17 ppm
9.	K	10 ppm
10.	TDS	600 mg/litre
11.	Ca	48 ppm
12.	Mg	19 ppm
13.	As	<0.1 ppm
14.	Ra-226	11.2 Bq/cu.m
15.	Th-230	<2.0 Bq/cu.m
16.	Po-210	22.8 Bq/cu.m

TABLE VI. ANALYSIS OF BULK ORE AND TAILINGS RESIDUE

S.No.	Element/Oxide	Bulk Ore (Feed) %	Tailings (Residue) %
1.	SiO_2	76.05	74.83
2.	Al_2O_3	12.72	12.57
3.	TiO_2	0.10	0.10
4.	Fe_2O_3	0.10	0.10
5.	FeO	0.70	0.30
6.	MgO	0.10	<0.10
7.	CaO	0.11	<0.10
8.	Na_2O	4.10	3.88
9.	K_2O	5.28	5.21
10.	P_2O_5	0.20	0.15
11.	MnO	0.02	0.02
12.	Moisture	<0.10	0.50
13.	LOI	0.50	1.70
14.	Ra-226 Bq/kg	5167.00	7150.20
15.	Th-230 Bq/kg	1314.20	919.60
16.	Po-210 Bq/kg	4356.80	4923.50

TABLE VII. GAMMA RADIATION LEVEL AROUND HEAP LEACHING PLANT, JAJAWAL

S.No.	Location	Radiation Level (uR/Hr) Pre-Operation	Post Operation
1.	On road to heap leaching site	17-20	13-18
2.	Around acid storage plant	18-20	15-20
3.	Site office room	20-24	20-22
4.	Chemical laboratory	20-24	20-28
5.	Change room	15-18	23-27
6.	Site stores	18-20	20-24
7.	Near ion exchange column	17-20	62-210
8.	Leach liquid tanks	22-26	19-22
9.	Near neutralization tank	20-24	20-24
10.	Ore stack	110-240	130-250
11.	North of leach pad	40-60	60-70
12.	East of leach pad	40-60	66-87
13.	South of leach pad	25-28	62-76
14.	West of leach pad	30-38	58-63
15.	3 km east of plant	7-18	10-20
16.	8 km east of plant	7-19	9-18
17.	13 km east of plant	10-18	10-16
18.	2 km east of plant	9-11	10-17
19.	5 km west of plant	10-12	10-15

Derived limit — 1000 uR/hr.

TABLE VIII. RADON DAUGHTER AND LONG LIVED ALPHA ACTIVITY IN AIR AROUND HEAP LEACHING PLANT, JAJAWAL

Location	Radon Daughter WL Concentration (WL)		Long Lived Alpha Activity Bq/cu.m	
	I	II	I	II
1. Plant site	0.006	0.0047	0.065	0.13
2. Leaching pad	0.007	0.0048	0.26	0.38
3. One km east of plant	0.008	0.009	<0.01	N.A.
4. Artesian well	0.015	0.017	0.44	N.A.
	DAC 0.33		DAC 0.48	

TABLE IX. CONCENTRATION OF ELEMENTS IN WATER SAMPLES AROUND JAJAWAL MINES AND HEAP LEACHING PLANT [11, 12]

S.No.	Sample location (Fig.2)	Ra-226 Bq/m^3	Th-230 Bq/m^3	Po-210 Bq/m^3	U mg/m^3	Cl g/m^3	PH	TDS g/m^3	SO4 g/m^3
1.	P I	30.1	--	--	2.3	33.1	6.7	398.0	18
	II	14.0	21.5	10.0	--	--		--	--
2.	IN I	13.2	--	--	1.0	33.1	7.6	429.4	18
	II	3.9±2.8	23.3±3.5	<2.0	--	--	--	--	--
	III	12.5	<2.0	12.8	1.41	<4	7.3	--	--
3.	IW I	39.3	--	--	1.0	20.6	6.9	439.10	15
	II	--	--	--	--	--	--	--	--
	III	8.3	<2.0	<2.0	--	--	--	--	--
4.	2N I	8.7	--	--	1.6	33.1	7.2	461.9	52
	II	<2.0	41.4±5.9	<2.0	--	--	--	--	--
	III	10.8	<2.0	12.2	--	--	--	--	--
5.	2W I	6.4	--	--	0.5	45.7	6.9	371.4	36
	II	9.5±2.8	22.2±3.3	<2.0	--	--	--	--	--
	III	9.2	8.1	25.0	0.90	<4	6.9	--	--
6.	3N I	27.2	--	--	1.2	8.1	6.8	372.60	15
	II	--	--	--	--	--	--	--	--
	III	7.8	<2.0	32.8	0.5	31	7.0	--	31
7.	3W I	8.7	--	--	1.2	20.6	7.0	472.20	<10
	II	--	--	--	--	--	--	--	--
	III	3.4	8.1	16.7	--	--	--	--	--
8.	4N I	--	--	--	--	--	--	--	--
	II	<2.0	20.7±3.0	<2.0	--	--	--	--	--
	III	3.9	<2.0	31.7	--	--	--	--	--
9.	4W I	30.0	--	--	1.1	8.1	6.0	90.0	10
	II	--	--	--	--	--	--	--	--
	III	3.4	3.0	6.1					
10.	5W I (4 km Wof4m)	9.1	<2.0	<2.0					
	DWC	500	700	700	200	200			200

I, II — Pre-operational measurement.
III — Post-operational measurement.

TABLE X. ANALYSIS OF SOIL SAMPLES IN AREA SURROUNDING HEAP LEACHING PLANT AND JAJAWAL MINES [12]

S.No.	Sample Location (Fig-2)		Ra-226 Bq/kg	Th-230 Bq/kg	Po-210 Bq/kg	U_3O_8 (ppm)	Mn (ppm)
1.	S1	I	24.6±5.0	168.1±9.0	23.6±3.5	4.5	510
		II	21.1	68.4	20.0		
2.	S2	I	46.0±7.0	349.0±13.0	47.4±4.2	3.5	1020
		II	33.3	32.0	50.2		
3.	S3	I	32.6±6.0	236.9±11.0	34.4±4.2	3.0	750
		II	74.3	30.0	37.1		
4.	S4	I	44.6±6.7	160.0±9.0	77.8±5.3	3.5	530
		II	20.2	109.1	86.0		
5.	S5	I	30.5±5.7	69.2±6.0	28.2±3.8	3.5	1520
		II	52.5	26.2	12.9		
6.	S6	I	24.5±5.0	182.6±10.0	32.2±3.5	3.5	530
		II	21.6	156.0	29.3		
7.	S7	I	50.1±7.4	203.1±10.0	34.9±4.2	4.0	1590
		II	9.2	149.3	17.3		
8.	S8	I	50.1±7.4	104.1±7.0	24.1±3.0	4.0	700
		II	17.0	139.5	15.3		
9.	S9	I	--	--	--	--	--
		II	14.4	68.4	14.6	3.5	710
10.	S10	I	--	--	--	--	--
		II	24.3	22.2	8.0	3.5	685
11.	S11	I	--	--	--	--	--
		II	14.4	15.1	4.0	4.0	750

I — Pre-operational measurements
II — Post-operational measurements

TABLE XI. VEGETATION ANALYSIS - JAJAWAL HEAP LEACHING PLANT

		U mg/kg	Ra-226 Bq/kg	Th-230 Bq/kg	Po-210 Bq/kg	Mn gm/kg
Red grass near tailing site	I	0.05	1.05	0.83	1.53	0.011
	II	0.06	1.24	1.01	1.73	0.015
Grass near leaching site	I	0.66	1.64	1.84	1.67	0.067
	II	0.70	1.70	1.85	1.50	0.060
Papaya near leaching plant	I	0.048	0.085	7.84	2.45	0.012
	II	0.057	1.69	5.13	2.98	0.011

I — Pre-operational
II — Post-operational

down stream sections of plant (S.No.4 to 10 Table IX) do not indicate appreciable enhancement in the analyzed radionuclides. This indicates that there is very little contamination of environment through seepage. Water of the stream beyond effluent discharge point has analyzed 3.4 to 3.9 Bq/cu.m. for Ra-226, <3.0 Bq/cu.m. for Th-230 and <6.1 Bq/cu.m. for Po-210, indicating that proper treatment of effluent can save the environmental degradation.

Papaya fruit (Papaya-indica) growing in the plant area has shown average intake of 1.69 Bq/kg of Ra-226 while other radionuclides show marginal increase from the pre-operational stage. This has been managed by destroying the fruits. Radiological monitoring at successive stages in Jajawal has clearly demonstrated that controlled discharge of effluent and seepage containment can help in maintaining radio-elemental balance.

The exploratory/developmental mining as well as commercial mining of uranium in India has clearly demonstrated that the strict implementation of the current safety parameters and their constant monitoring at successive stages of exploitation and simultaneous remedial measures, will immensely reduce the radiation hazards.

Ventilation in underground mines is of primary importance having direct bearing on the health of the working personnel. Regular ventilation monitoring and adoption of sound practices of ventilation are essential ingredients. Stringent measures before the release of mine waters and seepage monitoring help considerably in reducing environmental impact. Efforts are made to reduce residual impacts to as low as reasonable achievable (ALARA) targets.

Heap leaching has been undertaken with a view to establish technological expertise for leaching of low grade uranium ores following the current safety considerations. The experiments have clearly demonstrated that strict adherence to the stipulated regulations and constant monitoring of environment can eliminate the radiological hazards associated with uranium mining and heap leaching. Thus low grade small uranium deposits as well as large tonnage low grade deposits can be used for recovery of uranium without going for uneconomical commercial exploitation of such deposits which would also involve greater radiological hazards.

At the end it can be concluded that the current practice of generating baseline data for each project before starting any mining and continued environmental assessment and review process, have helped India in limiting the hazardous impact of uranium mining on the socio-ecological system.

ACKNOWLEDGEMENTS

Authors profusely thank Shri D.C. Banerjee, Director, Atomic Minerals Division for giving encouragement for preparing the paper and giving opportunity for its presentation. Motivation given by Shri Rajendra Singh, Associate Director, AMD has immensely helped in safe management of project work. Dedicated work by many scientists and technicians has made this task of safety management easier.

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ENVIRONMENTAL CONSIDERATIONS ON URANIUM AND RADIUM FROM PHOSPHATE FERTILIZERS

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Abstract

In the process of fertilizer production from natural phosphates of sedimentary origin, most of the existing radioactivity will be found in the final product. The phosphates exploited for fertilizer production at about 150 mill. tons/year are processed by two chemical methods: sulphuric and nitric acid attack. In the process of sulphuric acid attack of the phosphate rock, phosphoric acid and phosphogypsum are produced. The first product is used for fertilizer production, either as triplesuperphosphate (TSP) or diammonium phosphate (DAP). The phosphogypsum waste is deposited on stacks thus becoming a source of concern. In the case of nitric acid attack, the result is a phosphonitric (PN) solution, which is used to produce a complex fertilizer NPK. Uranium and 226Ra (usually in secular equilibrium) are dissolved and distributed between the intermediary products. Thus the average concentration of 100 mg/kg U in the phosphate rock is dissolved in 90–95 % in phosphoric acid while the 226Ra of initial 1000 / 2000 Bq/kg concentration is completely precipitated together with phosphogypsum. Therefore phosphogypsum waste has 1000–1500 Bq/kg 226Ra. The TSP fertilizer being produced by partial neutralization of phosphoric acid with phosphate rock with 100–150 mg/kg U, while 226Ra is only introduced in the neutralization process i.e. 500–800 Bq/kg. In the case of DAP, the uranium content is 140–170 mg/kg without the present of 226Ra. The complex fertilizer obtained through the process of nitric acid attack will have the whole uranium and radium of the phosphate rock (both are dissolved in nitric acid) with uranium and radium contents of 120–160 mg/kg, 1000–1500 Bq/kg respectively. The radio-activities of fertilizers produced may be a source of concern since both uranium and radium are exceeding the present accepted limits for their disposal in the environment. About 10,000–15,000 tons/yr. of uranium is spread every year on the agricultural lands worldwide by the use of phosphate fertilizers. In the case of phosphogypsum, there are regulations prohibiting its use in agriculture, construction industry etc., due to its 226Ra content. However, there is no such a rule in the case of fertilizers. There are several recovery plants for uranium from phosphoric acid based on solvent extraction, but as a consequence of unfavourable uranium market some of them were have been closed. However, the profitable consideration that should be taken into account in connection with the uranium recovery, should be the production of a non-radioactive fertilizer. We have developed a simple uranium recovery process in Romania based on a one cycle extraction-stripping principle. This process was successfully demonstrated in a big pilot plant of 7 m^3/h phosphoric acid capacity. The process was extended to industrial scale and three plants were built in Romania. This process was extended to the nitric acid attack that resulted in the elimination of 226Ra. Thus in both cases, either in sulphuric acid or in nitric acid attack, the final product is a non-radioactive fertilizer. The two flowsheets of the process are given is this paper.

1. INTRODUCTION

The natural phosphates of sedimentary origin which represent about 85% of those exploited for fertilizer production were found to be radioactive [1]. Uranium and its decay products were the source of this radioactivity. Radium is the main radioactive member of the series, which is in equilibrium with ^{222}Rn [2].

A special attention was given to uranium from sedimentary phosphates starting in 1950 [3]. At that time all new sources of uranium were screened for the fast developing nuclear programmes.

Phosphate fertilizer industry has also much extended requiring about 150 mil.tons/year natural phosphates [3]. Since average uranium content of phosphate rock was 100 mg/kg [4, 5] it is easy to estimate a non negligible 10–15,000 t/yr. uranium wasted at the same time with the fertilizer spread on agricultural lands. It is an important energy source lost and also a health hazard [6, 7].

In order to obtain a phosphate fertilizer, the phosphate rock undergoes an acid attack resulting an intermediate product phosphoric acid containing more than 90% of uranium in the liquid phase which is easy do be recovered. Since the mining costs are supported by the fertilizer plant, uranium eventually recovered is a by product obtained at lower costs.

For this reason in the booming era of nuclear programmes, uranium price soared to USD 100/kg or even more being a serious incentive to build several recovery plants in USA and elsewhere attaining a recovery capacity of 4,000 tons/yr. uranium in the phosphate fertilizer industry. However this booming era reached its peak in 1978–1982 then followed an interval of decreasing trend which in 1989 had much affected the uranium industry with its market marginal in profits [8].

In the last 10 years uranium price dropped to 20–25 USD/kg and immediate consequence was the closure of many mines and uranium industry suffered an important setback, uranium from phosphate being not excepted of these phenomena even if some plants survived.

Uranium recovery for nuclear purposes is one aspect of the problem. However there is another aspect related to environmental contamination by uranium and its decay products mostly ^{226}Ra. Since some existing regulations impose a limit on uranium disposal at about 0.2 mg/kg and for radium at 50–80 Bq/kg, for various other sources no such rules are given. It is known that most of phosphate fertilizer have 100 mg/kg Uranium content which are spread annually on agricultural lands and the same time also 700–800 or 1400–1500 Bq/kg ^{226}Ra. Some consider these values are not relevant in the case of fertilizer on the ground that only small radio-activities are involved, but in other cases it is relevant.

2. RADIOACTIVITY OF NATURAL PHOSPHATES

Sedimentary phosphates are radioactive, uranium being in equilibrium (exception are also possible) with ^{226}Ra (and ^{222}Rn) while some volcanic phosphates like those of Kola have traces radioactivity (slight trace of thorium). In this paper uranium and radium were determined in various phosphate [9, 10] feeding the four Romanian fertilizer plants (sulphuric acid attack) and other four fertilizer plants by nitric acid attack, each plant having 330,000 tons/yr. phosphate capacity. The results are given in Table I.

Most of sedimentary phosphates are radioactive. As long as the phosphate deposits are not disturbed (exploited), the natural environmental radioactivity is given by surface layers, the rest is contained in the mass of the rock. Rain waters may disturb this equilibrium and some radioactivity is carried by surface waters contaminating the surrounding agricultural lands. Phosphate exploitation zones may also be a source of concern like those of Florida contaminating large areas [11] due to beneficiation processes. As a result of beneficiation processes, sand and clay are separated of phosphate mineral and are disposed of in ponds. The phosphate clays resulted in the washing process and slimes are pumped to large settling areas. The clay is allowed to settle and water is recirculated. It was believed that settling areas would become waste lands due to radioactive contaminants. However using modern machines the drain of clay surface is feasible and the land reclamation is a process much speeded. Various plants as alfalfa were used to speed the drying process. The land reclamation is a process carried out in 3–5 years. Problems related of working the clay areas were minimized. The phosphatic clay is a fertile soil unique to Florida. Special steps were taken to grow agricultural crops on reclaimed lands. A project was developed but the problem were the uranium and radium distribution in the crops. Thus ^{226}Ra content is of the order of 500–600 Bq/kg compared with common soils of 30 Bq/kg. Therefore plants grown on phosphatic soils accumulate higher radioactivity and the pickup is dependent on the type of crop, and for the same plant they are differently distributed between roots, stem and leaves. Therefore the milk had higher ^{226}Ra content when cows were fed with alfalfa grown on phosphatic clays.

We have insisted on this subject since a similar behaviour might be extrapolated on agricultural lands fertilized every year with phosphate fertilizer.

TABLE I. URANIUM AND RADIUM IN COMMERCIAL NATURAL PHOSPHATES

Phosphate deposit from	Type	U content mg/kg	^{226}Ra content Bq/kg
Florida	Sedimentary	100–150	750–1500
Florida	11	80–100	600–800
Carolina	11	80–120	600–1000
Morocco	11	100–160	800–1600
Tunis	11	30–50	250–350
Algeria	11	100–120	700–850
Israel	11	80–140	800–1200
Jordan	11	80–110	800–900
Togo	11	100–110	950–1000
Senegal	11	100–120	950–1100
Curacao	11	20	--
Kola	Volcanic	20	70

3. RADIOACTIVE DISTRIBUTION IN THE PROCESS OF FERTILIZER PRODUCTION

There are two main processes for fertilizer production starting with natural phosphates: sulphuric and nitric acid attack.

i) Sulphuric acid attack (dehydrate process)

This is by far the most important process discussed here and is based on the chemical reaction:

$$Ca_{10}(PO_4)_6F_2 + 10\,H_2SO_4 + 20\,H_2O \rightarrow 6\,H_3PO_4 + 10\,CaSO_4{*}2H_2O + 2HF$$

From this process, two product resulted:

(a) phosphoric acid (liquid phase) where more than 90% of uranium of the rock is found. No radium is present.
(b) gypsum, usually named phosphogypsum, is the solid phase which carries the whole amount of ^{226}Ra that initial found in the phosphate rock. Phosphogypsum may also carry 5–10% of uranium of the rock.

Since they are dependent on the phosphate rocks used in the process, the following uranium and radium contents are given in the resulted phosphoric acid of 1.25–1.27 density (24–28% P_2O_5). The measurements were based on gamma spectrometry, NAA, X ray fluorescence.

TABLE II. URANIUM AND RADIUM CONCENTRATION IN PHOSPHORIC ACID

Phosphate rock used	Uranium mg/L	^{226}Ra Bq/L
Florida	120–140	40–70
Jordan	80–100	30–50
Morocco	120–160	30–60
Israel	90–110	40–50
Togo	100–110	60
Senegal	100–100	70
Kola	5–10	--
Syria	70–90	60
Egypt	80–100	50
Tunis	40–60	40
Algeria	80–100	60

Therefore most of the uranium in the rock was dissolved and the ^{226}Ra was virtually absent being precipitated in the phosphogypsum. The phosphogypsum analysis is given below:

TABLE III. URANIUM AND RADIUM CARRIED BY PHOSPHOGYPSUM

Phosphate rock used	Uranium mg/kg	^{226}Ra Bq/kg
Florida	10–20	500–1200
Jordan	5–10	500–1000
Morocco	10–15	600–1300
Israel	10–20	600–1200
Tunis	5–8	300–400
Kola	--	60–100
Togo	10	700–1100

Table III confirms the data of Table II.

Phosphoric acid, the intermediate product, is separated from the phosphogypsum and is used for the production of fertilizer. The phosphoric acid is concentrated to 45–50% P_2O_5 and then reacted with phosphate to produce triplesuperphosphate (TSP) according to reaction:

$$14H_3PO_4 + Ca_{10}(PO_4)_6F_2 + 10H_2O \rightarrow 10Ca(H_2PO_4)_2H_2O + 2HF$$

Such a fertilizer includes all uranium in the phosphoric acid and also those in the phosphate rock used in the neutralization process as well as the whole ^{226}Ra of the rock. Therefore the TSP fertilizer from sedimentary rock has an average 80–140 mg/kgU and 300–700 Bq/kg ^{226}Ra. If Kola phosphate rock was used in the phosphoric acid neutralization then no radium was carried by TSP.

The alternative, where phosphoric acid is neutralised with ammonia, the fertilizer produced is usually DAP (diammoniumphosphate). In the alternative of DAP the radioactivity involved is that of the phosphoric acid and therefore no radium is present.

Uranium and radium contents for various TSP and DAP fertilizer are given in Table IV.

TABLE IV. URANIUM AND RADIUM IN VARIOUS FERTILIZERS (SULPHURIC ATTACK)

Phosphate rock used	TSP		DAP	
	U mg/kg	^{226}RaBq/kg	U mg/kg	^{226}RaBq/kg
Morocco	120	400	140	40
Jordan	90	300	100	30
Florida	130	450	140	40
Israel	120	400	120	50
Tunis	60	150	70	30
Kola	--	30	--	30

If uranium is eliminated and recovered by solvent extraction then the TSP uranium content is minimized and in the case of DAP no radioactivity is present. However there are also natural phosphates of much higher radioactivity resulting from uranium phosphates content which may be 20–30 times higher than that met in commercial phosphates. In this case radium follows a similar trend and its high radioactivity in phosphogypsum is of a great problem. Some literature data [2, 4, 6] on uranium content in the phosphate rock is given in Table V.

TABLE V. PHOSPHATE DEPOSITS OF HIGH URANIUM CONTENT

Phosphate rock used	Uranium mg/kg
Brazil	1200
Central African Republic	1600–5600
Siberia (depressions)	up to 4000
Utah	up to 3000
India	up to 800

The high uranium content of phosphate rock is a health hazard and the radioactivity must be removed from phosphoric acid before producing a fertilizer. The alternative, the production of TSP must be avoided and replaced by DAP.

ii) Nitric acid attack of phosphate rock

In this process the rock is completely dissolved including uranium and radium which are found 100% in the liquid phosphonitric (PN) solution [12]. The advantage of the process is that nothing like phosphogypsum was produced. In the process of fertilizer (complex) production of this type the calcium nitrate $Ca(NO_3)_2 4H_2O$ is usually separated by strong cooling as a solid crystallized product which is later converted to NH_4NO_3 and $CaCO_3$ by $(NH_4)_2CO_3$. Our determinations have shown that no radioactivity was present in the separated $Ca(NO_3)_2 4H_2O$ and therefore no radioactivity was carried in the solid $CaCO_3$. Thus the whole uranium and radium from the initial rock are present in liquid PN solution, after the separation of $Ca(NO_3)_2 4H_2O$.

In the process of complex fertilizer production of NP(K) type the PN solution is neutralized by ammonia. Therefore the end product contains the entire uranium and radium. This is shown in the following table VI.

TABLE VI. URANIUM AND RADIUM CONTENT IN THE NP FERTILIZER PRODUCED

Phosphate rock used	Uranium mg/kg	^{226}Ra Bq/kg
Florida	100–120	1000–1200
Morocco	100–130	1200–1300
Algeria	90–100	1000–1100
Israel	90–100	900–1100
Jordan	80–90	800–900

In this table, it is noted that uranium and radium of the phosphate rock are present in the produced fertilizer. Even in this case where ^{226}Ra concentration is similar or higher than in the case of phosphogypsum no regulations are given for complex fertilizers, but the use of phosphogypsum is forbidden. Uranium in phosphogypsum is negligible but in the case of complex fertilizer the uranium is added to the existing radium. However the Regulating Authority is not issuing limits in this case.

Radium removal from complex fertilizer is a simple matter. In our determination based on classical coprecipitation of Ra by $BaSO_4$ it was possible to eliminate at one stage about 80% of ^{226}Ra from PN solution after $Ca(NO_3)_2 4H_2O$ separation. A better elimination is feasible at higher yield if Ba^{++} and SO_4^{-}ions are introduced with a flocculant at the clarification stage of PN solution destined for uranium and rare earth recovery by solvent extraction. Solids involved in this process are 5% and usually are recirculated in the fertilizer process. Therefore we have introduced Ba^{++} and SO_4^{-}ions just before neutralization of PN solution by ammonia. In this condition $Ba(Ra)SO_4$ has precipitated and was separated by filtering. About 80% of radium was removed while Habashi mentioned [3] 90% yield, in different conditions. In Table VII the radioactivity of ^{226}Ra in the PN solution is given before and after precipitation process.

After this treatment a complex fertilizer produced will maintain its uranium content but radium is now 150–250 Bq/kg. A further treatment on $BaSO_4$ in another stage may reduce it still further to 100Bq/kg. However, the uranium is left in the fertilizer.

In the next stage Uranium and Rare Earths are recovered by solvent extraction and the end product (fertilizer) has 10 mg/kg Uranium.

TABLE VII. RADIUM ELIMINATION AS BA(RA)SO4 IN PN SOLUTION

^{226}Ra in PN solution Bq/l	% ^{226}Ra removed
1500	83
1200	80
1100	81
1000	78

4. RADIOACTIVITY REMOVAL FROM PHOSPHATE FERTILIZERS

A simple process for uranium recovery from phosphoric acid and a slightly modified version for uranium and radium removal, including rare earth recovery, from PN solution are given in this paper. Based of these versions, two ways of eliminating uranium and radium from phosphate fertilizer are suggested. In the case of sulphuric acid attack the process experimented at pilot scale of 7 m^3/h phosphoric acid capacity, led to the construction of three uranium recovery plants in Romania. At the same time that uranium is obtained for nuclear purposes, as UF_4xH_2O, the produced fertilizer had a low radioactivity. Since the purpose of this work is for the production of fertilizer with very low radioactivity, the processes used are given below for the two cases: sulphuric and nitric acid attack of the phosphate rock.

In the case that no treatment is involved, uranium and radium from the phosphate rock are found in the final fertilizer at various contents. If the alternative of phosphoric acid (sulphuric attack) treated by solvent extraction to remove uranium is selected, the end product, TSP, has only the radioactivity contributed from the phosphate rock in the reaction with phosphoric acid. If Kola volcanic rock is used for this purpose, the resulted TSP has no radioactivity (Fig. 1).

In the case of DAP, no radioactivity is involved, but the uranium has previously been removed by solvent extraction. Starting with PN solutions, first ^{226}Ra has to be removed as $Ba(Ra)SO_4$ then uranium (and rare earth) is extracted and eliminated. The final complex fertilizer (NP type) has a very small radioactivity (Fig. 2).

However phosphogypsum is still a problem due to its ^{226}Ra content and the large amounts stacked near the fertilizer plants. In Romania there are millions tons of phosphogypsum near the 4 existent fertilizer plants, which is a source of concern due to fine particles spread by the wind and ^{222}Rn continuos evolution. No rehabilitation works were involved to cover these stacks with soil and vegetation to stop the environmental pollution. Most of the countries have introduced regulation and have drastically reduced phosphogypsum use in agriculture and construction industry.

In the case of fertilizers like those produced by nitric acid attack, the radioactivity is even higher than that of phosphogypsum since in addition to ^{226}Ra of the same concentration uranium is also present at 140–180mg/kg. No regulation is involved and no Regulating Authority imposes any restrictions on fertilizer use, and the radioactivity being completely neglected. It must be noted that 10,000–15,000 tons/yr. uranium is spread on agricultural lands every year worldwide attended by corresponding radium. At the same time uranium is a heavy metal (the heaviest) and also toxic [13, 14] chemically. There are regulations imposing drastic limits on heavy elements in fertilizers but uranium is neglected. It was already shown

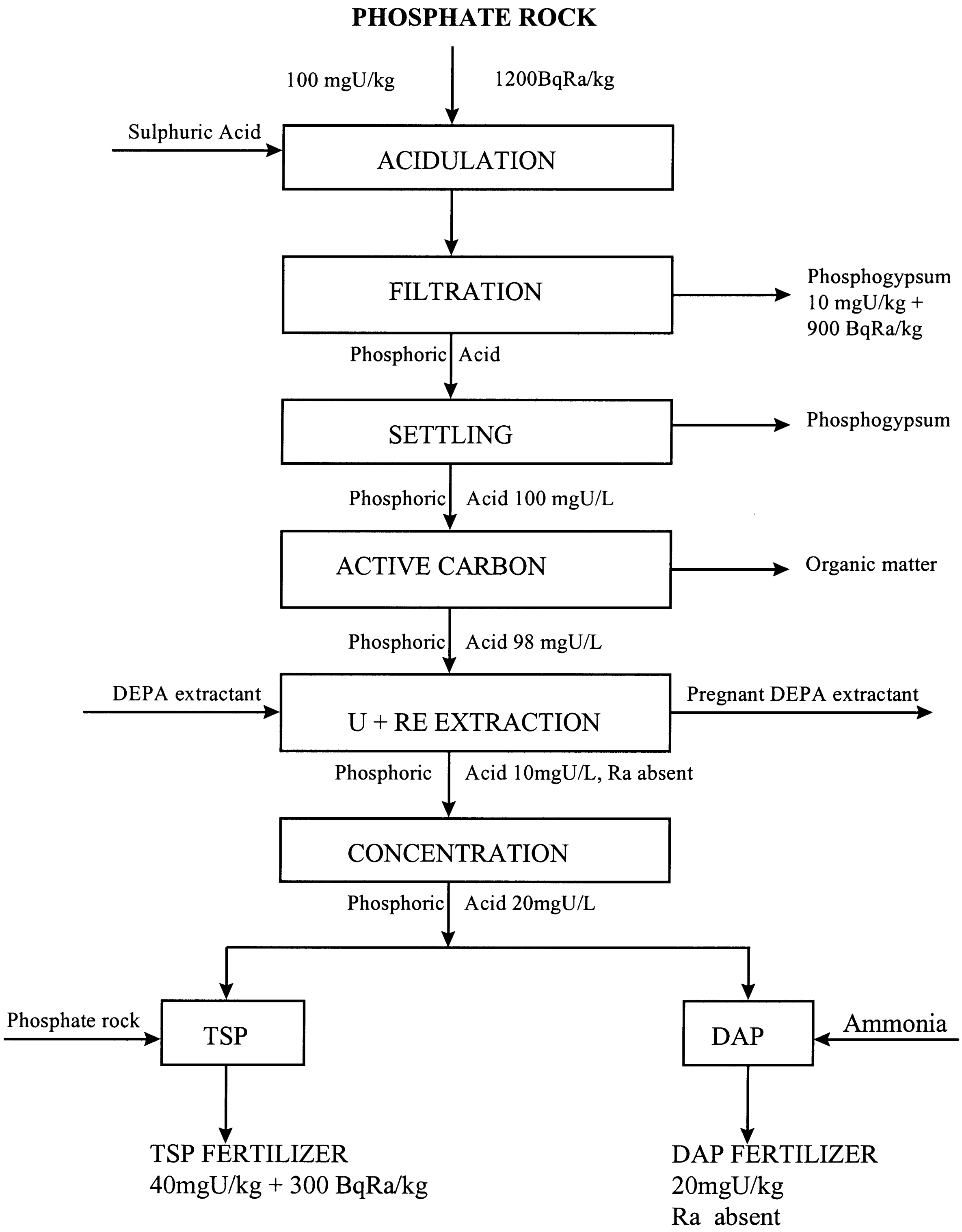

FIG.1. Uranium and radium removal in the process of sulphuric acid attack of phosphate rock for fertilizer production.

that various crops accumulate radioactivity and that ^{226}Ra might be found in milk, but until now no steps were taken to curb the radioactivity in the fertilizers used.

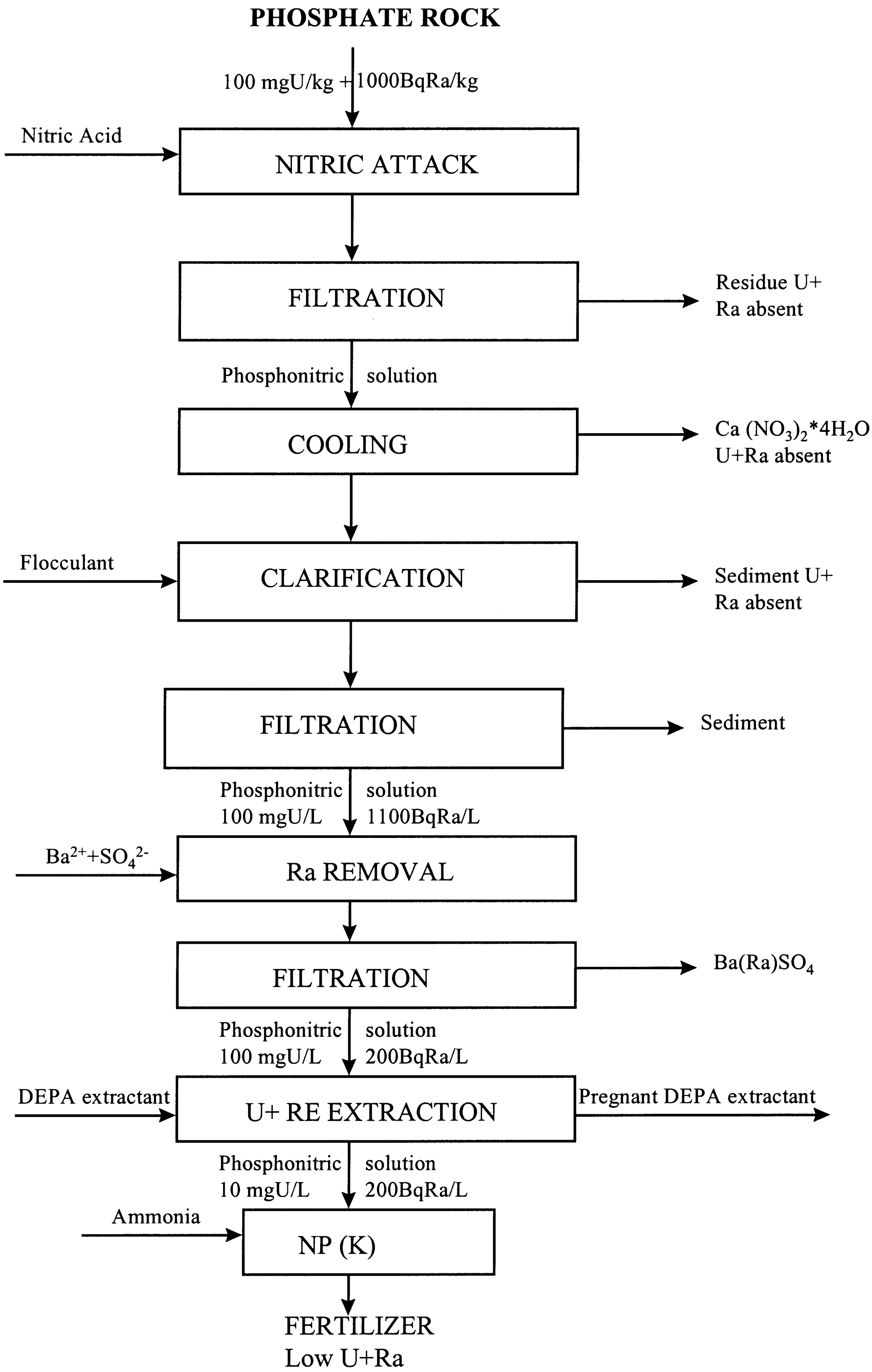

FIG. 2. Uranium and radium removal in the process of nitric acid attack of phosphate rock for fertilizer production.

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IMPACT OF ICRP-60 ON THE OPERATION OF UNDERGROUND MINES

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Summary

Reduction of occupational exposure from: 50 mSv to 20 mSv per annum for uranium miners faces difficulties. For miners this affects the gamma radiation dose and ALI's except radon gas and its short lived daughters of Uranium and Thorium whereas the ICRP planned to review radon daughters exposure limits. New dose limits introduce other mines, e.g. phosphate mines, to be considered as occupational areas. Reclassification of radiation workers has to be done; control, licensing, cost, Gamma dose rate is influenced by the grade and type of ore body and the mining method. The primary mode of radionuclide intake in the mine environment is inhalation however, ventilation is the principal control of airborne dust. The current average radon daughters dose rate in several underground mines among those are phosphate mines in Egypt is well above 20 mSv/a. Recorded values of Egyptian phosphate mines are more than 1 WL of radon daughters (1WL = 62 uSv/h) considering 2000 h/y, therefore, the annual dose = 124 mSv/a.

Mining method dictated by location, size and shape of ore body, hydrology. Priority is given for conventional safety of work place, e.g. rock collapse as well as care of economics of the process and mine development. It is well defined that the control of gamma radiation dose is very much dependent upon the geometry of ore body. Shielding of ore trucks could not be justified (fuel consumption and its pollution). Bulk ore handling method may reduce gamma doses but it generates dust which may increase inhalation doses of long lived alpha emitters. Ventilation is the principal method to control inhalation hazards of dust and radon daughters, but high rates of ventilation has reverse effects of generating more dust and drying wet surfaces of ores.

Accordingly, reduction in radon daughters exposure will result in high cost of production. In Egypt radon and thoron (risk\problems) are previously monitored in phosphate mines (upper Egypt).

Values greater than 1 WL were measured in many locations of those phosphate mines. Those mines have sufficient radon daughters concentration that workers should be classified as radiation workers.

Considerable financial burden on operating mines, regulatory considerations would be required if ICRP-60 is to be adopted. Moreover detailed studies and data are required, on weighing factors of organs considered by ICRP-60 which has to be reviewed to the local conditions. Total radiation work period of 50 y is considerably long compared to miner work period of 20 y. The relevant conventional health hazards are to be considered.

Dose limits (ICRP-60)

For internal exposure, annual limits on intake will be based on a committed effective dose of 20 mSv. The estimated intakes may be averaged over a period of 5 years to provide some flexibility.

The occupational limits for radon are under review.

Conventional safety considerations

(a) Gamma dose rate is influenced by the grade and type of ore body and the mining method.
(b) Mining method is dictated by location, size and shape of ore body.
(c) Priority for conventional safety of work place, e.g. rock collapse.
(d) Economics of the process and mine development.
(e) Shielding of ore trucks could not be justified.

Radiation levels in conventional mines (Phosphate mines in Egypt as example)

In Egypt radon and thoron are previously monitored in phosphate mines.

(a) Values > 1 WL were measured in many locations of those mines.
(b) These mines have sufficient radon decay product concentrations that workers should be classified as radiation workers.

Considerable financial burden on operating mines, regulatory considerations, would be required if ICRP-60 is to be adopted.

(c) The following table (Table I) shows some detailed levels in phosphate mines.

Study of the effect of natural ventilation in phosphate mines to save the costs of mechanical ventilation

(a) This will help in case ICRP-60 is also adopted for phosphate mines.
(b) Good correlations are obtained between radon and thoron concentrations and the distance from air openings.
(c) The followings are example for this study.
(d) The study shows that natural ventilation may be used as economical measure to decrease radon and thoron concentration.

Study of radon flux as a way for the estimation of radon levels in some mines in the design stage

This study will help in providing economical mean to estimate radiation hazards in the design stage.

This will help in case ICRP-60 is adopted to decrease the costs of safety measures.

Best fitted mathematical models and correlation factors for West Yonus mine

(a) *Radon in $\mu J/M^3$ — against distance in meter:*

Linear : $Rn(X) = 0.0087\ X + 2.441$, $R^2 = 0.7851$

Polynominal : $Rn(X) = -1\ E - 13\ X^6 + 1E - 10X^5 - 5E - 8\ X^4 + 8\ E - 6\ X^3 - 0.0007\ X^2 + 0.028\ X + 2.6019$

$R^2 = 0.9991$

TABLE I. A SUMMARY OF EXPOSURE RATES, EFFECTIVE DOSE AND ANNUAL DOSE IN PHOSPHATE MINES

Location	Point of study	Gamma & Beta level (mR/h)	Radon decay products (WL)	Effective dose equivalent (uSv/h)	Annual dose for the workers (mSv/y)	Temperature and humidity (°C, %)
SAFAGA Area South Mine	1	0.03	1.283	83.19	121.46	26°, 85
	2	0.03	1.174	76.38	111.51	26°, 85
	3	0.03	0.959	62.94	91.89	24°, 80
	4	0.03	0.984	64.5	94.169	26°, 80
	5	0.03	0.939	61.69	90.067	24°, 80
	6	0.03	0.887	58.44	58.32	28°, 80
HAMRAWEEN Area Mine B	1	0.03	0.451	31.19	45.45	25°, 72
	2	0.03	0.708	47.25	68.98	26°, 75
	3	0.03	1.225	79.56	116.16	27°, 87
	4	0.03	1.009	66.06	96.45	27°, 87
	5	0.03	0.817	54.06	78.93	27°, 85
	6	0.03	0.624	42	61.32	26°, 80
EL-QUSER Area Youns mine C	1	0.25	0.034	4.625	6.75	26°, 82
	2	0.25	0.095	8.44	12.32	26°, 62
	3	0.25	0.157	12.31	17.97	26°, 82
	4	0.25	0.261	18.81	27.46	27°, 85
	5	0.03	0.476	32.75	47.46	27°, 85
	6	0.03	0.671	44.94	65.61	27°, 87

(1) EPA document No. OPA-86-004 (1986)
(2) IAEA Safety Series No. 43, (1976)
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(4) ICRP Publication No. 60 (1990)
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Logarithmic : $Rn(X) = 0.7336 \, Ln(X) + 0.2081$, $R^2 = 0.5429$
Power : $Rn(X) = 1.4488 \, X^{0.1928}$ $R^2 = 0.6136$
Exponential : $Rn(X) = 2.6225 \, e^{0.0022X}$ $R^2 = 0.8507$

(b) *Thron in $\mu J/M^3$ — against distance in meter:*

Linear : $(X) = 0.0045 \, X + 0.5202$ $R^2 = 0.8799$
Polynominal : $Th(X) = - 4E - 12 \, X^5 + 3E - 9X^4 - 9 \, E - 7 \, X^3 + 0.0001 \, X^2 - 0.0064 \, X + 0.8763$, $R^2 = 0.9639$
Logarithmic : $Th(X) = 0.3835 \, Ln\,(X) - 0.6616$, $R^2 = 0.6695$
Power : $Th(X) = 0.2213 \, X^{0.3378}$ $R^2 = 0.6655$
Exponential : $Th(X) = 0.6346 \, e^{0.0038X}$ $R^2 = 0.8769$

(c) *Radon in $\mu J/M^3$ — against thoron in $\mu J/M^3$:*

Linear	:	$Rn(Th) = 0.4577 (Th) - 0.5325,$	$R^2 = 0.8998$
Polynomial	:	$Rn(Th) = 0.0188 (Th)^5 - 0.2143 (Th)^4 + 0.2643 (Th)^3 + 4.986 (Th)^2 - 20.985 (Th) + 24.77,$	$R^2 = 0.9592$
Logarithmic	:	$Rn(Th) = 1.8846 \ln (Th) - 1.2653$	$R^2 = 0.932$
Power	:	$Rn(Th) = 0.1496 (Th)^{1.5502}$	$R^2 = 0.8486$
Exponential	:	$Rn(Th) = 0.277 e^{0.3728 (Th)}$	$R^2 = 0.8035$

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MANAGING RADIOACTIVE WASTE ISSUES AND MISUNDERSTANDINGS (RADIATION REALITIES, ENERGY COMPARISON, WASTE STRATEGIES)

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Abstract

The technical specialist is confident that radioactive waste can be safely managed, but many in the public remain totally unconvinced. There are issues and deep-seated misunderstandings that drive public doubts. Currently, a growing concern with pollution from other industrial waste is enabling radioactive waste issues to be debated in a wider context that allows comparisons with other potentially hazardous waste, particularly from energy generation sources. Health effects and time period issues are not unique to radioactive waste. This paper concentrates on 3 topics. The first concerns radiation health effects where the real realities of radiation are covered. The large misunderstandings that exist about radiation and its health effects have led to an almost zero health impact regulatory policy. A policy which must be more fully understood and dealt with. The second topic deals with a few revealing comparisons about the various energy generation systems. Nuclear power's 10 thousand fold lower fuel requirements, compared with a comparable fossil fuelled plant, is a dominating factor decisively minimising environmental impacts. The third topic examines waste disposal strategies. Extraordinarily small radioactive waste quantities permit a confinement strategy for disposal as opposed to the more common dispersion strategy for most toxic waste. The small quantities coupled with radioactive decay, contrary to the public perception, make any potential hazard from both low and high level radioactive waste exceedingly small.

Radiation Realities

Turning to *radiation realities*, there is an "**anxiety about radiation and an *exaggerated perception* of its health effects (that) has resulted in an essentially *zero impact* regulatory policy".**

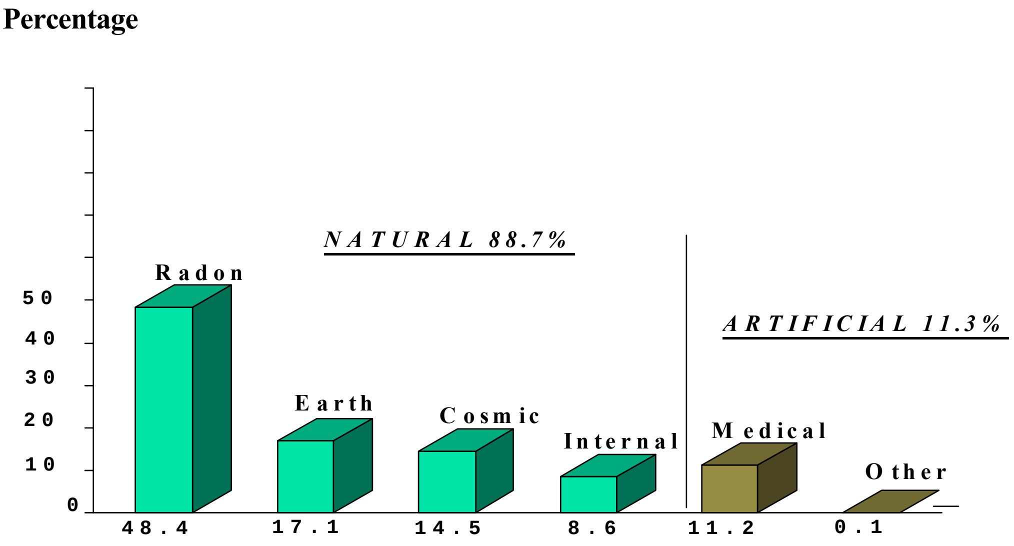
That there is an exaggerated perception of radiation effects is demonstrated in a few figures that follow which put artificial radiation exposures into perspective with the large and very variable natural background radiation, and which also show the known radiation health effects of the atomic bomb survivors since they are the principal bases for current health effects models.

The *zero impact regulatory policy* that we currently live with is rather unique as it actually governs only some small *additions* to the much larger background exposure we receive everyday. In this context, a look at what we do and what we do not regulate is revealing.

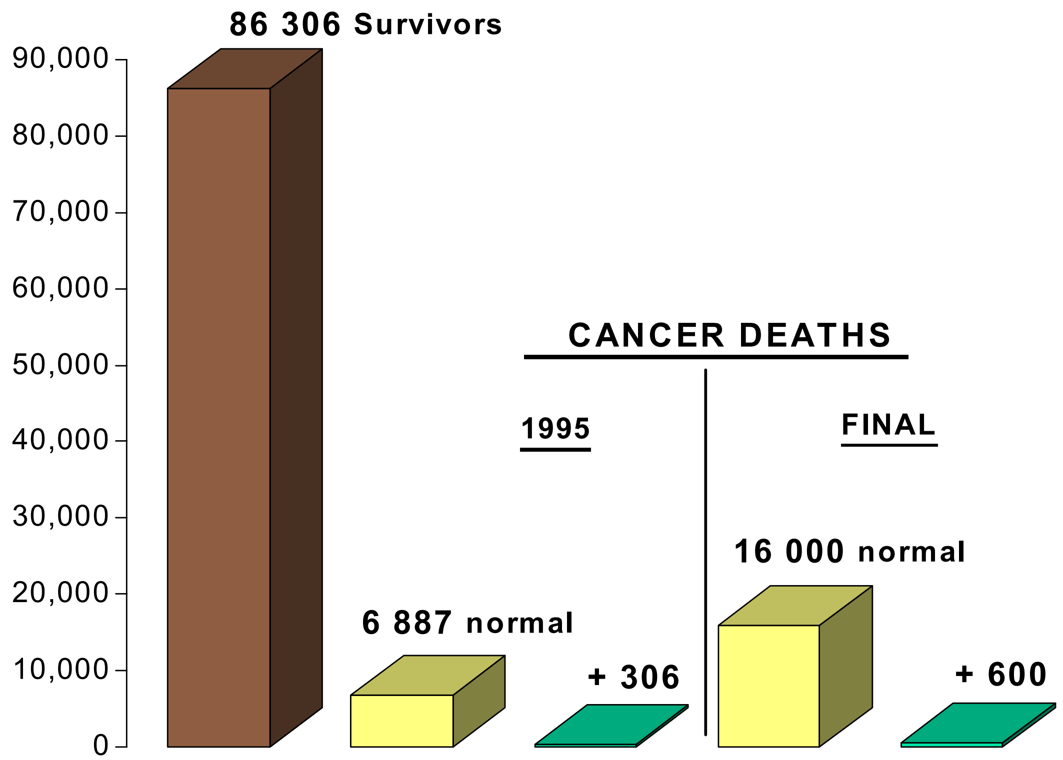
We are all continually exposed to cosmic radiation and natural radioactive elements are in the *air* we breath, the *earth* we walk on, the *homes* we live in and in the *food* we eat as well as in our *bones and tissues*. In comparison to this ongoing and unavoidable exposure from *natural background* sources, exposures from artificial sources are small.

The artificial exposure itself is almost totally medically related, with routine nuclear power activities contributing only a *fraction of one percent* to our total exposure, an addition which can best be characterised as *minor*. As shown later, the natural background is dependent on location and can vary by many multiples of ten, making any nuclear power related exposure even less meaningful.

Annual Individual Radiation Exposure
(2.7 mSv total)



Atomic Bomb Survivors

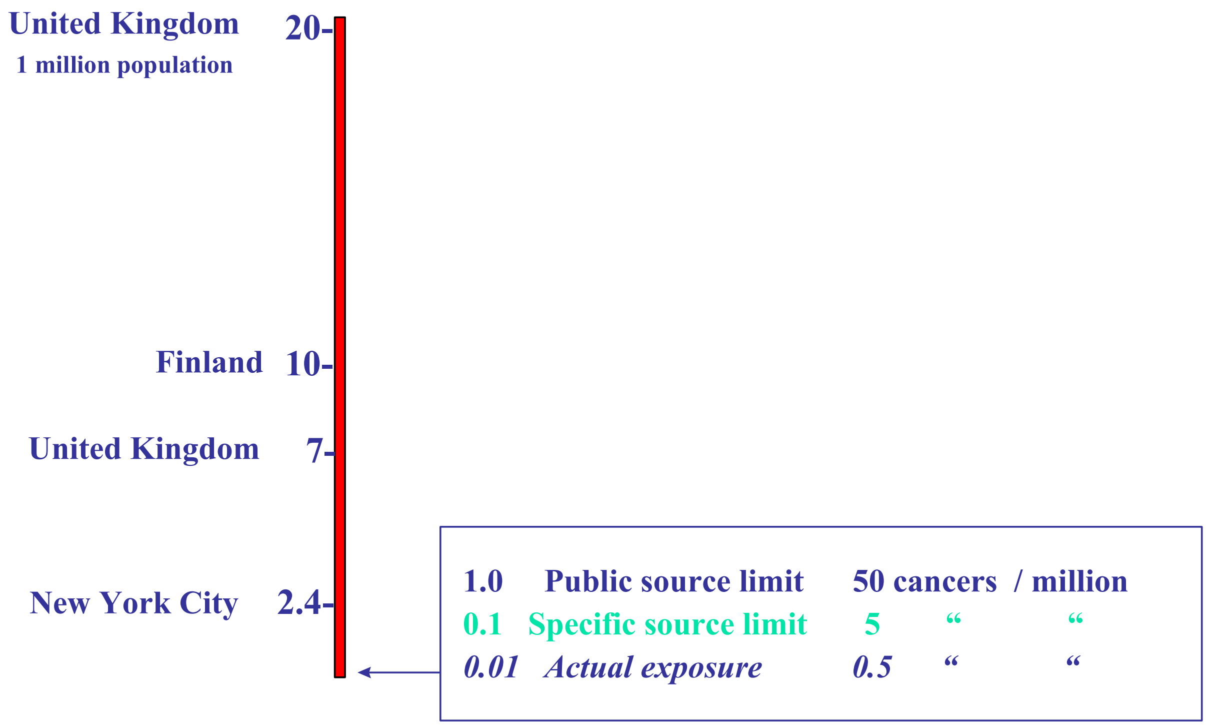


Extreme high radiation exposures of three to four thousand times natural background cause breakdowns in body functions leading to severe disability or death within a short time. Much lower level exposures can cause radiation induced cancers, principally late in life. The Radiation Effects Research Foundation in Hiroshima has over the past 50 years carried out an epidemiological study of 87 000 atomic bomb survivors who were exposed to moderately high radiation levels.

As with all populations, about 20% will die from non-radiation induced or so called normal cancers. The epidemiological studies are indicating additional cancer deaths, currently estimated at some 300. Studies continue with a projected eventual total of some 600 radiation induced cancer deaths that are concentrated in the more highly exposed, an overall addition of 0.7% to the normal 20% rate. An expected several year loss in the survivors' average life expectancy will not materialise as above average health care through early diagnosis and treatment of medical disorders, including cancer, is leading to increased longevity. There are many people in the public and technical community who are not aware of these results and believe that the health effects are considerably greater, and also that considerable abnormalities have occurred in the descendants. But, no above normal number has been demonstrated in the 80 000 children and more than 100 000 grandchildren and great grandchildren.

The RERF study provides a significant perspective. Health effects from moderately high radiation exposure can occur. Nevertheless, when viewed in the larger context of health effects in general and particularly severe incidents, they are relatively small.

Variations in Background Radiation Exposures (mSv annually)

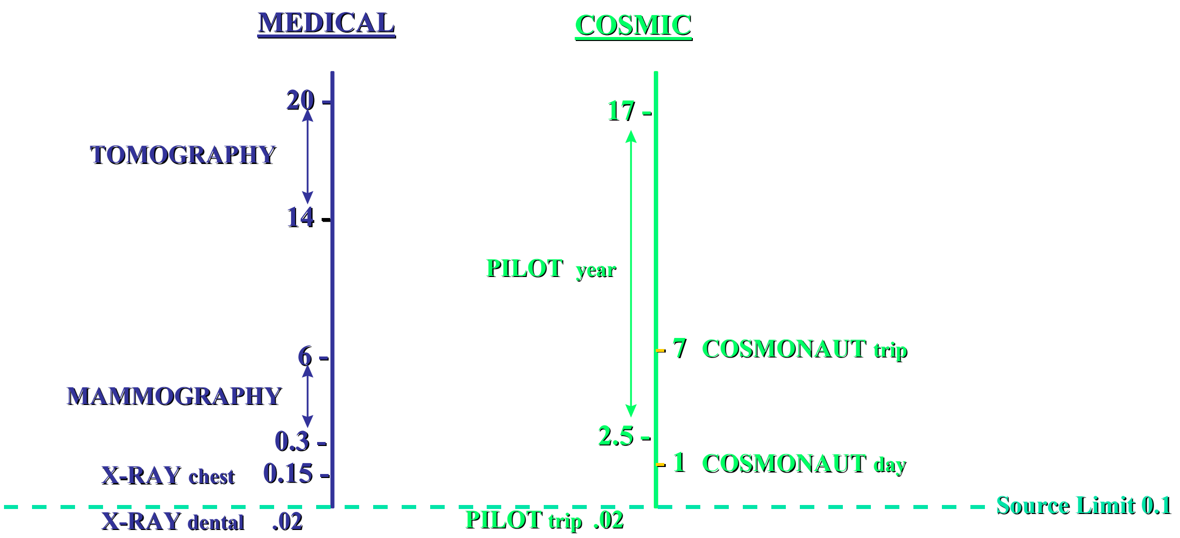


Turning to regulatory policy, today's strict safety regulations deal only with small *additions* to a much larger and unavoidable natural background. The background itself varies significantly by location due to radon gas with multiples of ten not uncommon. This unavoidable background is mostly excluded from regulations as it is simply not feasible to reduce this exposure except through relocation and unacceptable restrictions on individual lifestyles.

For regulated sources, as shown on the left, the *total* additional yearly exposure for the public is limited to 1 mSv or 40% of the world average background. Based on ICRP models, such an exposure of *every* person in a population of 1 million people would add 50 radiation cancer deaths to some 200 000 normally expected in the population's lifetime. For a *specific* regulated source, such as a nuclear power plant, the exposure is limited to as low as 10% of the total. This could lead to 5 cancer deaths if every person were exposed to the limit. However, only a small fraction of the population could possibly be continuously exposed over an entire year to accumulate this limit. Thus, in effect, today's regulatory requirements allow for only a fraction of the estimated 5 cancer deaths, or likely not one. On a probability basis, the individual likelihood of incurring a cancer is comparable to initially drawing all four aces from a full deck of playing cards and having the first card of a second deck also being an ace.

Is such a zero health effects policy reasonable or sensible? If it were applied to other industries, the economic consequences would be enormous. Applied to automobiles, to eliminate the 50 000 deaths that occur each year in Europe and also in the United States, we could require everyone to drive a multi-million dollar steel plated tank down our highways and through our cities.

Unregulated Exposures (mSv)

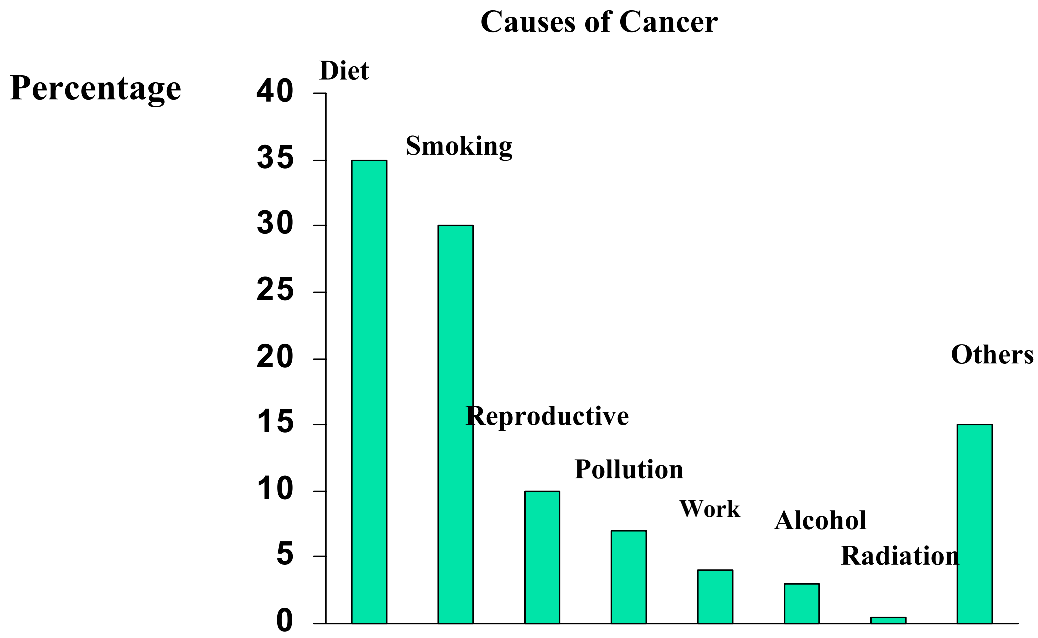


Now for a look at the numerous relatively high exposure situations that are not strictly regulated because control is impractical or they are judged beneficial. In addition to medical exposures, those to airline crew, airline passengers and the relatively large exposures to cosmonauts are not regulated. Actual in flight measurements show that exposures from eight return transatlantic flights or four flights to Asia would exceed the individual public source limit of 1 mSv. One short airline trip in Europe could be equal to one year's actual exposure form living near a nuclear power plant.

Airline pilots commonly receive higher exposures than radiation workers at nuclear power plants, but any attempt to classify them as radiation workers would have serious operational and economic implications for airlines. Cosmonauts receive several times one years' natural background exposure during a typical voyage.

Once again, is such a regulatory policy reasonable or sensible? Whether or not there is an actual threshold for low level radiation effects, a rational and sound regulatory policy may require assuming a realistic exposure level, below which one can assume there is no health effect of concern.

A perspective on radiation cancer effects can be seen by the various causes of cancer deaths. Diet and smoking cause chemically induced cancers accounting for some one-third each of all cancer deaths, with alcohol and environmental pollutants causing an additional few percent each. The remainder is due to a variety of causes with any impact from routine nuclear power activities immeasurably small.



Energy Comparisons

Turning now to the second topic that considers energy comparisons. Huge quantities of a wide variety of waste are produced annually worldwide . Its minimisation is a key element for environmentally sustainable development.

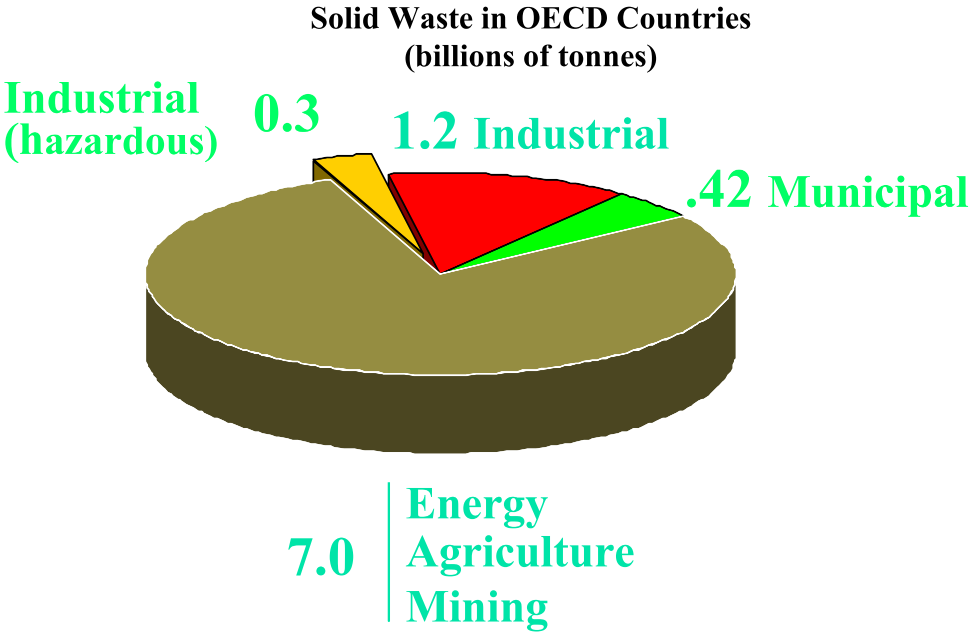
"Nuclear power's *10 000 fold lower* fuel requirements, compared with fossil plants is a dominating factor *decisively minimising* its waste and other environmental impacts". We will rapidly scan a few figures that illustrate the various types of waste being produced, and then turn to some comparisons of the quantity of radioactive waste compared to the quantity of noxious, toxic and polluting waste from fossil fuel sources that currently supply the overwhelming share of world energy, some 87% of primary energy needs.

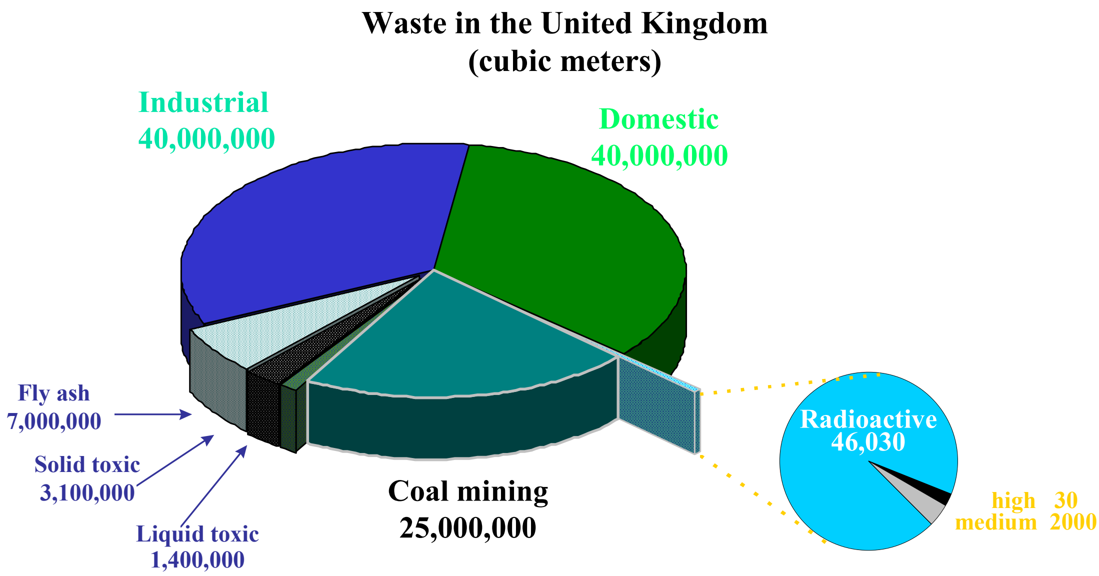
There are some 9 billion tonnes of solid waste in the OECD countries that can be grouped into industrial, energy related, agricultural and mining. There are some 300 million tonnes of hazardous waste from industry.

The small quantity of radioactive waste is seen by the various types and volumes of waste produced in the UK. There is almost 5 million cubic meters of liquid and solid toxic waste compared with some 46,000 cubic meters of all types of radioactive waste.

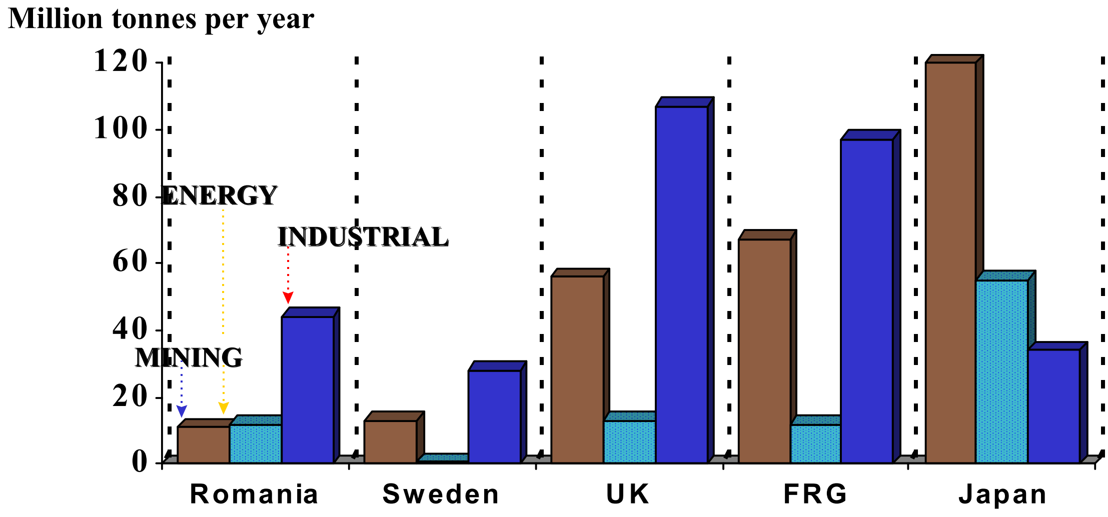
Although varying by type, the quantities of UK waste are not very different in Germany or Japan.

Turning now more directly to a comparison between nuclear and fossil fuels, there are some basic similarities in the fundamental processes. But, what is strikingly dissimilar and not seen on this figure is, as I have already noted, the large 10 000 fold difference in fuel requirements between nuclear and fossil fuels and of course the large resultant difference in waste products for equal amounts of energy generation.

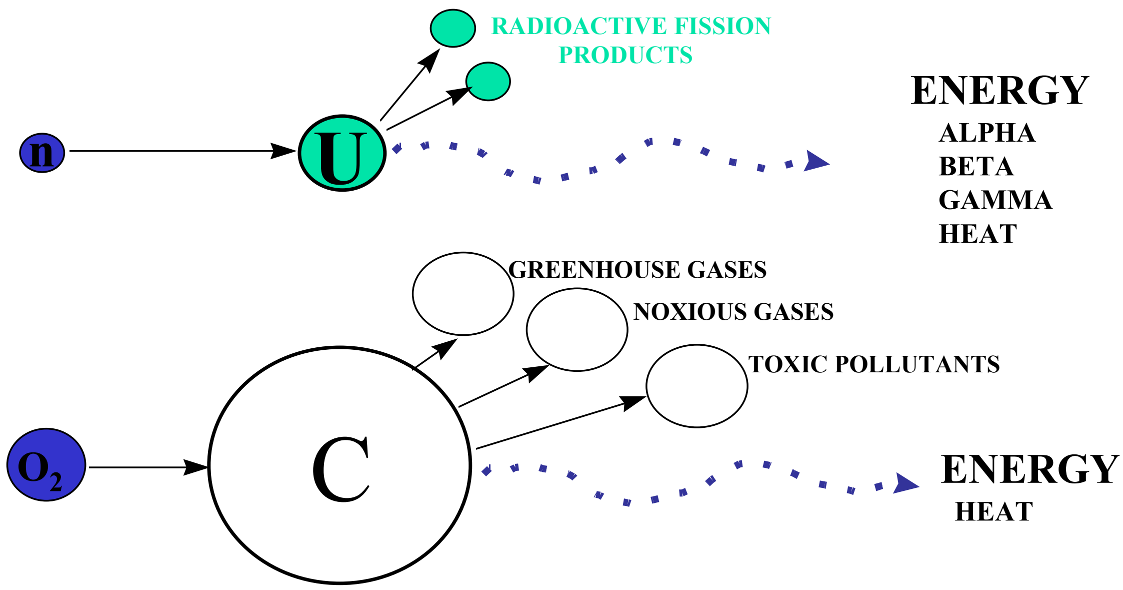




Annual Industrial Waste



Energy Comparisons



The large difference in fuel requirements is seen by the figures for a 1000 MWe power plant where *2.6 million tonnes of coal and 2 million tonnes of oil are required, compared with just 30 tonnes of uranium*. Transport requirements are some *2 thousand train cars each with 1300 tonnes of coal, 10 supertankers for oil, and 1/3 of a reactor core for nuclear, which is equal to some 10 cubic meters.*

What makes the vast difference in nuclear fuel requirements a dominating factor for our environment is the ever growing quantity of energy needed, driven in a large part by a rapid growth in population. Today's population of 6 billion is twice the figure only 50 years ago, and is 6 times the 1 billion at the turn of this century. It could double again by the end of the next century.

Although varying considerably by region, the current world average fuel demand per person is 1.6 toe yearly, which when multiplied by 6 billion people is 10 btoe worldwide . This figure will likely be at least 50% higher by mid-century.

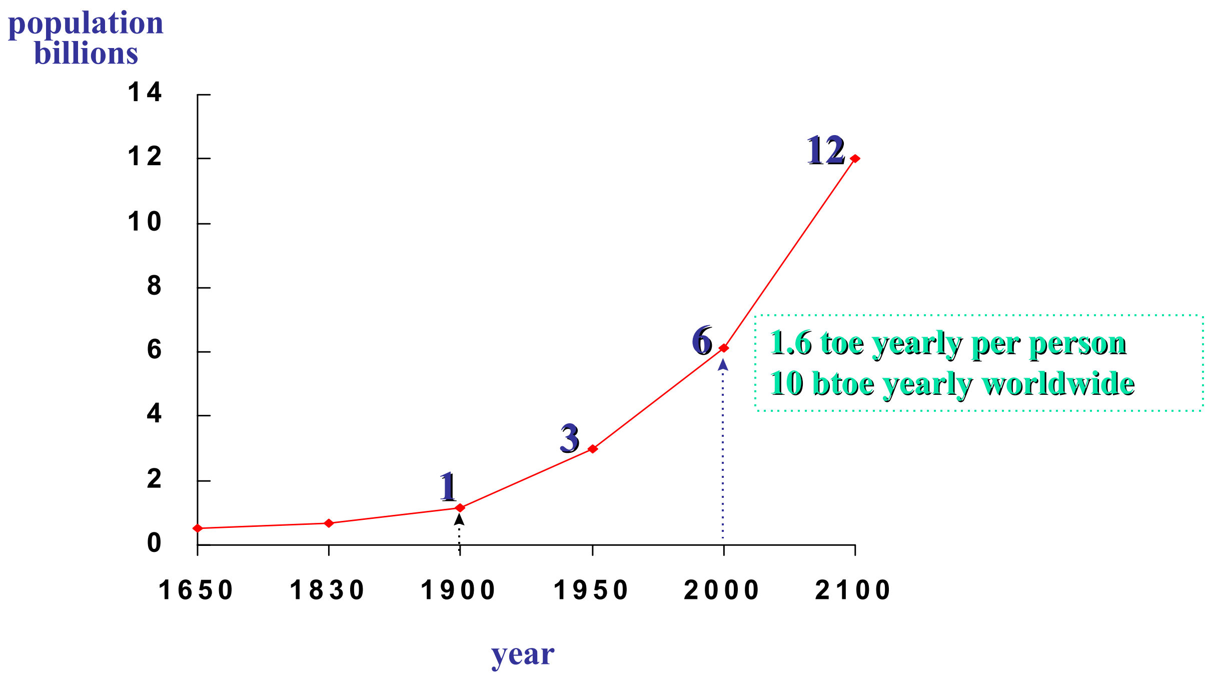
Fuel Required Annually
1000 MWe

COAL **2,600,000 t** - **2000 train cars** (1300 t each)

OIL **2,000,000 t** - **10 supertankers**

URANIUM **30 t** - **1/3 reactor core** (10 m³)

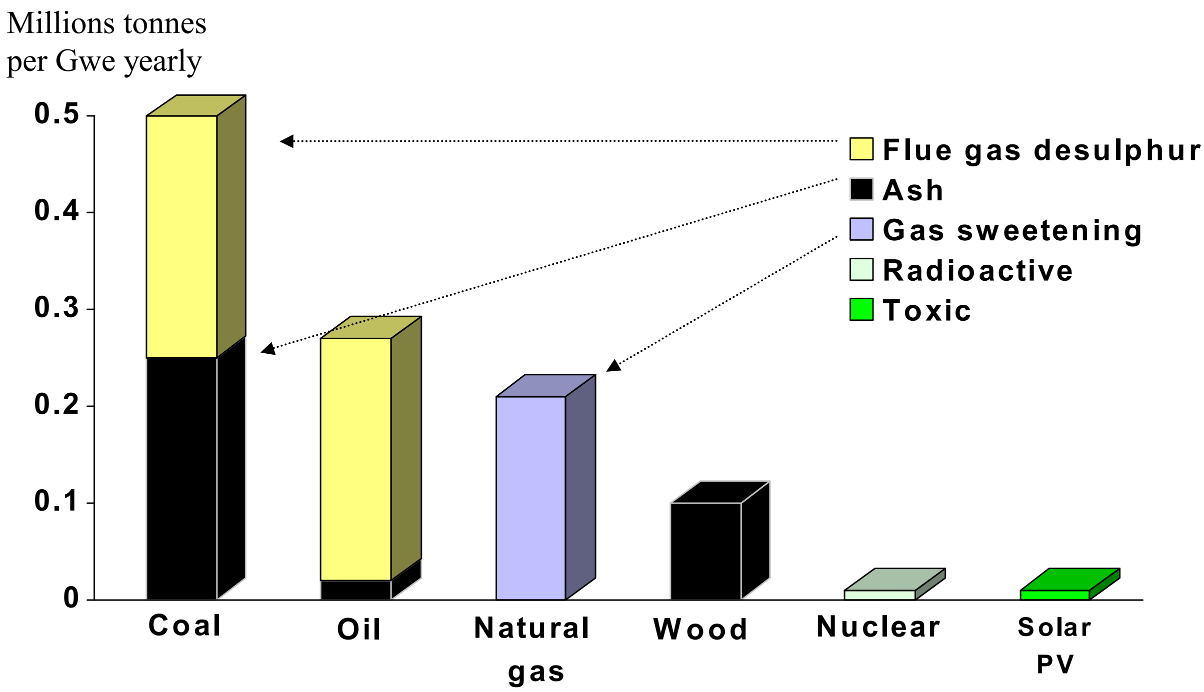
The Population Explosion



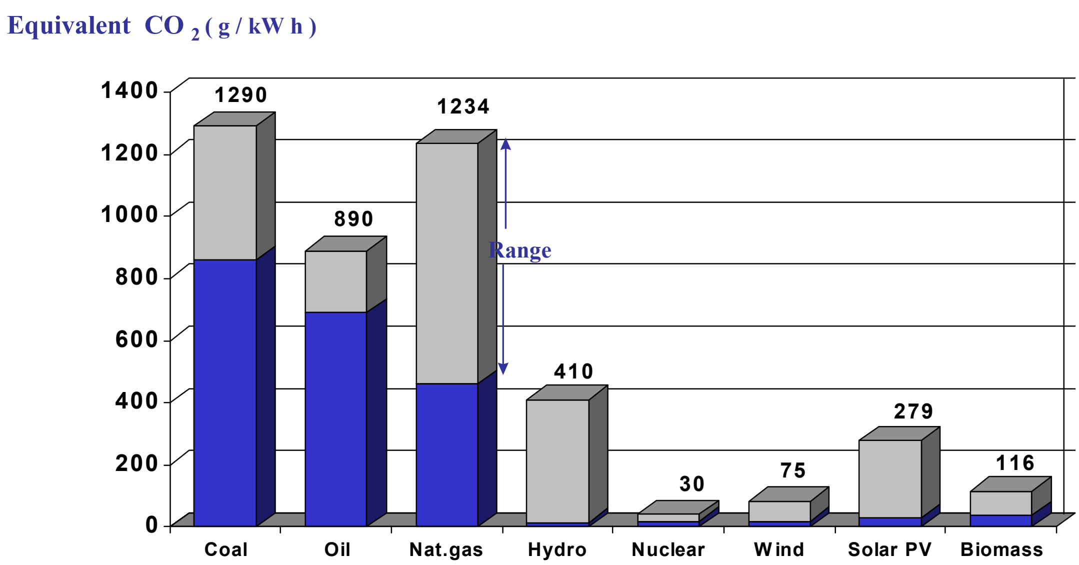
The large quantity of waste including those from noxious gas abatement procedures are shown in this figure. The ash from coal contains some 400 tonnes of chemically toxic substances. There is also some 1000 tonnes of particulates released into the atmosphere.

There are of course large releases of greenhouse gases from fossil fuels, including from natural gas where leakage in recovery and transport can be some 5%.

Waste in Fuel Preparation and Plant Operation

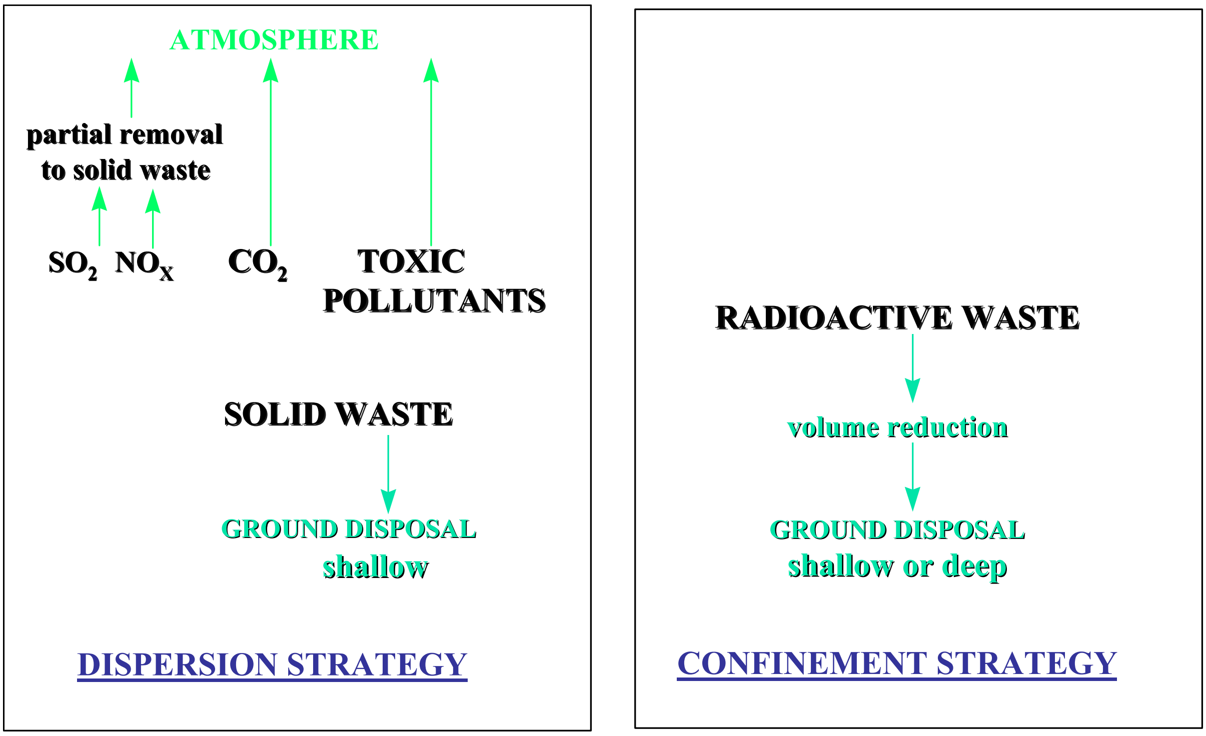


Full Energy Chain CO_2 Emission Factors



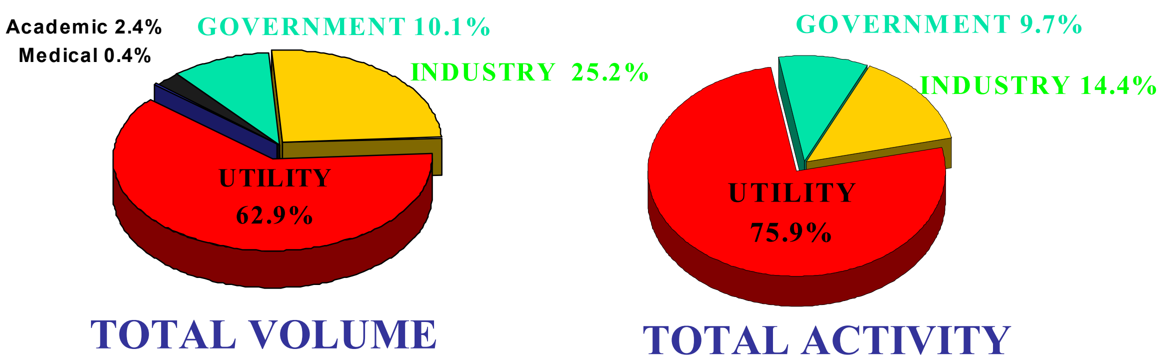
With some insights into the large differences in fuel and waste quantities, we can turn to the final topic on waste disposal strategies. What is strikingly different between the disposal of nuclear and fossil fuel waste, is the basic waste disposal strategy used. The small quantities of nuclear waste permit a *confinement strategy*, beginning with the nuclear fission process and continued to final waste disposal, a strategy essentially isolating the radioactive material from the environment.

Two Alternative Waste Strategies



In sharp contrast, disposal of the large quantities of fossil fuel waste follows an alternative *dispersion strategy*. Most of the waste — the noxious gases and many toxic pollutants are dispersed directly into the atmosphere while some solid waste containing toxic substances is buried in shallow ground, there being no practical alternative.

Low Level Waste in the USA (1996)



The next few figures are concerned with the makeup of radioactive waste — the various sources and quantities and its hazard potential.

As this figure shows, radioactive substances are used extensively in industry and by governments, and in medicine and research centers. A large share of low level waste arises from these non nuclear power activities. In the USA some 60% of the low level waste volume is from utilities operating nuclear power plants with a 25% share from other industries.

Industries with Enhanced NORM Material

PHOSPHATE: fertiliser, phosphoric acid	**URANIUM (feedstock)** **RADIUM (byproduct gypsum)**
ZIRCON SAND for refractories & ceramics	**URANIUM**
MONAZITE SAND for rare earth elements	**URANIUM, THORIUM**
OIL & GAS industry	**RADIUM (scales)**
METAL smelting	**BISMUTH, POLONIUM**
URANIUM mill tailings	**RADIUM, THORIUM**

During the past years, a radioactive waste source not related to nuclear energy applications has received growing attention. Large quantities of low level waste arise from industrial activities involving raw materials containing **naturally occurring radioactive material** such as uranium, thorium and potassium — so called *NORM* waste. The industrial activities include phosphate ore processing and the production of phosphate fertiliser along with oil and gas extraction.

Although regulatory concerns vary widely, contrary to the approach used for low level waste from nuclear power facilities, the NORM waste generally receives little attention. At the same time, some NORM waste is being managed as low level radioactive waste at significant and perhaps unnecessary cost.

Low Level Waste

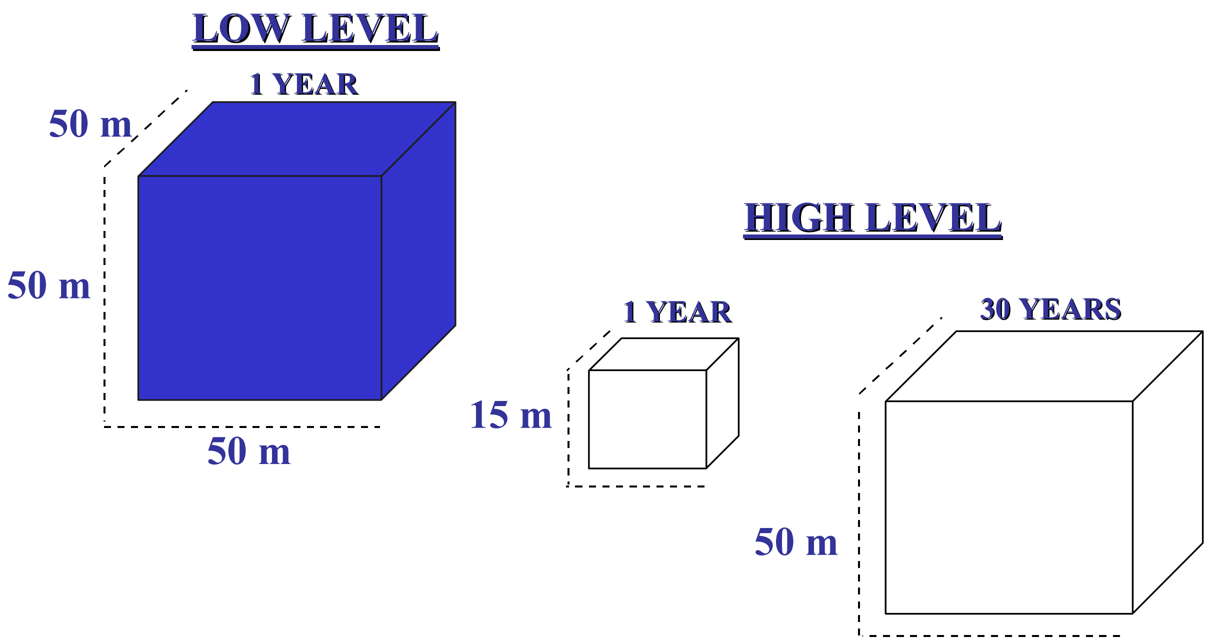
Contrary to public perception, **"the hazard from low level waste is exceedingly small as its radiation intensity is low. Relatively rapid decay limits the long term hazard potential to only some hundred years, with safe containment unquestionably feasible for this time period".**

The radiation levels of low level waste is sufficiently low so that simple protective measures — even for highly compacted waste — are adequate during handling. The levels are low enough that if fertiliser, Brazil nuts and coffee beans were produced at a nuclear site they would be treated as low level waste since they contain natural radioactive substances, such as radioactive potassium and radium.

Low level waste can be disposed of in simple near surface trenches. Although not dictated by radiation protection purposes, it is routinely isolated in engineered structures such as concrete lined trenches and vaults.

Most low level waste consists almost solely of short lived substances with less than 30 year half-lives. Thus, the radioactivity level decreases rapidly, about tenfold in 100 years and an additional tenfold in another 100 years.

Worldwide Waste Volumes



Before turning to some final remarks covering high level waste, a look at the total volumes of both low and high level waste from nuclear power plants is useful.

A typical nuclear power plant produces some 200 cubic meters annually, under 100 000 cubic meters from all operating plants worldwide — equivalent to a cube somewhat less than 50 meters on each side. The worldwide total of high level waste annually is some 4000 cubic meters, equivalent to a cube 15 meters on each side.

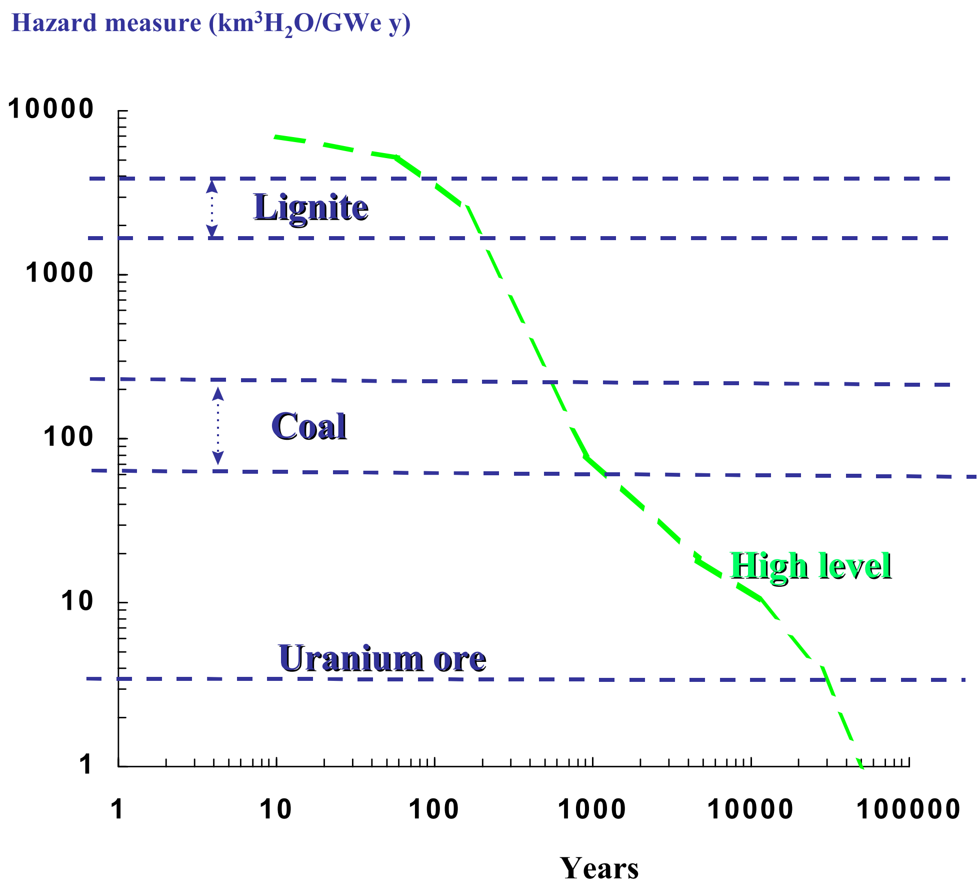
The total volume of high level waste produced over the next 30 years from today's operating power plants would be somewhat more than 120 000 cubic meters, equivalent to a cube some 50 meters on each side. Indeed, the quantities involved are remarkably small.

High Level Waste

"The hazard from deep underground repository disposal of high level radioactive waste is exceedingly small since many transport barriers and dilution by underground water would lead only to radiation exposures well below natural background levels". Contrary to this statement, the public believes it is extremely difficult or not possible to assure safe management of high level waste. But, high level waste contains only residual heat energy and a chain reaction or chemical explosion is physically not possible. Radiation from hundreds of meters below ground cannot reach the surface as it is absorbed in the engineered and natural barriers that isolate the radioactive waste. The only credible human radiation exposures would be in the distant future involving incidents caused by long term corrosion or mechanical forces. It would result in a limited and slow movement of radioactive substances to the surface, greatly diluted by underground water, potentially leading to only minimal individual exposures well below natural background levels.

Safety assessment models, along with natural analogues such as uranium deposits, confirm that the current multiple barrier concept would limit the quantity of radioactive substances reaching the surface. Nevertheless, the current regulatory approach calls for calculated exposures to be similar to those for normal releases from today's operating power plants, on the order of 0.1 mSv annually. Not only is the calculation process which considers time periods up to 1 million years unscientific, but also to limit exposures from an incident that may never occur to exceedingly low levels is not sensible. If limits are required, it would be more reasonable to use the intervention levels for accident situations which can be some 1000 times greater.

Radioactive and Fossil Fuel Waste Hazards



This final figure is concerned with the long lived nature of high level radioactive waste where time works in its favour as radioactive decay continuously decreases the hazard potential. But time is only one factor influencing the hazard potential, the quantity of waste being another. Hazard indicators that consider both factors have been developed. One such indicator compares the amount of water necessary to dilute the radioactive substances in nuclear power waste and the toxic substances in fossil fuel waste to admissible drinking water standards — the less water needed, the lower the hazard potential.

In some 100 years, high level waste from reprocessing would require less water than lignite waste, and in some 500 years less water than coal waste. It would be similar to uranium ore in under ten thousand years. The principle reasons are the small amount of radioactive waste and the relatively rapid decay of reprocessing waste as much of the long lived elements, such as plutonium, have been removed. Without reprocessing, the time periods increase, with radioactive waste approaching coal in several thousand years and uranium ore in some tens of thousand years, but not the many millions of years commonly perceived.

A balanced treatment of radioactive waste requires abetter understanding of the issues and an appreciation of the inconsistent approaches to radioactive and other hazardous waste. Ihope this paper has contributed to a better understanding .

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