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Planning and management of uranium mine and mill closures

Proceedings of a Technical Committee meeting held in Liberec, Czech Republic, 3-6 May 1994

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FOREWORD

The depressed uranium market since 1980 forced many producers to suspend their operations either permanently or temporarily. As a result, the world's uranium production has continued to decline following a trend that started notably in 1988. Worldwide uranium production in 1993 is estimated to be about 32 700 tonnes U, about 3500 tonnes less than the previous year's production. This represents only about 55% of the estimated 1988 production. Further decline is expected in 1994. The USA and eastern Germany provide extreme examples of these closure and/or suspension activities. In the USA over 350 mines and 25 conventional mills have been permanently or temporarily closed since 1980. The permanent closure and decommissioning of eastern Germany's WISMUT, the world's third largest national uranium producing industry, is expected to cost 13 billion DM over 10 to 15 years.

It is with this background that the Technical Committee Meeting on Planning and Management of Uranium Mine and Mill Closures was organized. The objective of the meeting was to bring together experts in the uranium industry and corresponding regulatory bodies to present and discuss their experiences in the planning and closure of uranium mines and mills. The emphasis of the meeting is on operational/engineering options as well as the economic aspect of facility closure, whether permanent or temporary.

The Technical Committee Meeting on Planning and Management of Uranium Mine and Mill Closures was held in Liberec, Czech Republic from 3 to 6 May 1994. A total of 30 participants from nine countries attended the meeting. Nineteen papers were presented. Most of these papers dealt with the concept of and experiences in planning for and the subsequent decommissioning and rehabilitation of uranium mines and mills in Australia, Canada, Czech Republic, Germany, Romania, Slovenia, Spain and the USA. Two papers discussed the government's role and relevant regulations related to the closures, decommissioning and remediation of uranium production facilities. Of particular interest to the participants was a non-technical paper presented by the Mayor of the city of Andujar, Spain, describing the negative political and socio-economic impacts associated with closure and decommissioning of a uranium mine/mill facility. The highlights of the meeting were the field visits to the uranium production facilities and rehabilitation programme sites of DIAMO and WISMUT companies, located respectively in Stráž, Czech Republic and Königstein, Germany.

The IAEA is grateful to the Government of the Czech Republic and in particular the DIAMO state enterprise for hosting and organizing the meeting. The IAEA is also grateful to the management of WISMUT GmbH of Germany for hosting the visit to their Königstein facilities. Special thanks are extended to participants who contributed papers and took part in the discussion. The untiring efforts of Mr. J. Slezák and his colleagues of DIAMO, who contributed to this successful meeting and field trip, are very much appreciated.

The IAEA staff members responsible for the organization and implementation of the meeting were M. Tauchid and D. Underhill of the Division of Nuclear Fuel Cycle and Waste Management.

EDITORIAL NOTE

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SUMMARY OF THE MEETING

The uranium industry has been facing a depressed market for over a decade and the future is still uncertain. This is despite the fact that the 1993 uranium production met only 55% of the world's nuclear reactor fuel requirement, and that existing stockpiles are rapidly being drawn down. A conservative figure indicates there were several hundred mines and over 100 mills in operation in the world during the production peak of the early 1980s. At present only about 150 uranium production facilities (mine, mill and in situ leach) are in operation. A number of production centres were closed because the resources were exhausted, but many others were closed, either permanently or temporarily, by the depressed market which made their operations uneconomic. It is for this reason that during the past decade many companies and relevant government authorities were actively closing, decommissioning and rehabilitating these facilities. The Technical Committee Meeting on Planning and Management of Uranium Mine and Mill Closures was held as a forum of exchange of information between concerned uranium industry experts and corresponding government regulators on the planning for and eventual closure of uranium mines and mills and their rehabilitation.

In recent years, uranium mines and mills have attracted public attention because of their impact on the environment and the associated radioactivity. This has occurred even though the impact is in many cases relatively small as compared with mining activities related to other commodities and fuels. Both the industry and government bodies concerned with this activity are constantly under public pressure to assure that any modifications of the environment caused by such an activity are not harmful to the public and generally meet high international standards of safety. This concern normally continues or even increases when such a facility is to be closed and decommissioned.

It has been shown that lack of adequate planning for closure, decommissioning and eventual rehabilitation of the older facilities has resulted in negative environmental impact. Frequently the public has been responsible for the financial burdens related to remedial actions. In many cases this was partly due to inadequate regulations at the time of development of the projects. In some countries premature closure of uranium production centres have also resulted in a negative socioeconomic impact on the surrounding community. At present, however, in most countries, no uranium production centre can be commissioned without a proper decommissioning plan and the assurance of its funding. These various problems were the subject of lively discussion during the four days meeting in which project descriptions from 8 countries, some with long histories of uranium production, were presented. It was obvious from these presentations that both the planning and actual closures of mines and mills and the subsequent site rehabilitation represent relatively new activities. In the future, new developments in design options are expected — reflecting different types of facilities in varying geographical and climatic conditions, as well as different uranium deposit types.

Two topics of great interest throughout the meeting were the cost of, and the responsibility for decommissioning and rehabilitation, particularly for older and abandoned facilities. Papers presented from Australia (Ring et al.), France (Daroussin and Pfiffelmann), Germany (Mager), Slovenia (Jeran), Spain (Morales and López Romero, and Perez Estevez) and the United States of America (Chung) include a wide range of costs. Even experiences within a single country (Spain), suggest quite different approaches, and therefore differing costs. This may indicate the lack of acceptable international standards and practices regarding how such an undertaking should be carried out.

Most of the papers stressed the importance of using site specific designs. For this to be effective, the understanding and the need for appropriate baseline information is of prime importance. A statement in the paper by Ring et al. summarizes the general consensus of the experts "... that planning and proper waste management during the operational phase are the key to cost effective and environmentally acceptable decommissioning of a uranium mine and mill." It was also noted that public involvement in uranium facility closure programmes results in much better understanding and acceptance of these activities.

THE ROLE AND ACTIVITIES OF THE STATE OFFICE FOR NUCLEAR SAFETY IN URANIUM MINE AND MILL CLOSURES

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Abstract

Uranium production in Czechoslovakia began in 1946. Cumulative production coming from 20 production centres to the end of 1993 is in the order of 103 000 t U. Almost all of these centres are located in the Czech Republic. At present only two centres are still in operation. The Czech Republic is now confronted with control, monitoring and eventual rehabilitation of these closed centres. The State Office for Nuclear Safety (SONS) is charged with the responsibility of controlling of nuclear safety of all nuclear facilities, including operating and abandoned uranium mines and mills, which was performed previously by the Czechoslovak Atomic Energy Commission (CAEC). Present activities of SONS in this areas have focused on the siting, construction and operation in the storage and transport of uranium concentrate. A number of laws and regulations related to radioactive waste, radiation protection, environmental protection, clean water system, as well as the construction, commissioning and eventual decommissioning of nuclear facilities have already been adopted. Regulations specific for nuclear fuel cycle facilities are under preparation.

The Czech Republic has a very long tradition in uranium mining and milling. These activities were performed by state holding company CSUP (Czechoslovak Uranium Industry) which has been recently renamed to DIAMO. This company is under supervision of the Ministry of Trade and Industry.

The Czechoslovak Atomic Energy Commission (CAEC) until December 31, 1992, before dividing Czech and Slovak Federal Republic (CSFR) into two states Czech Republic and Slovak Republic, has not been involved on state supervision on nuclear safety [1] at the mining and milling facilities operating by DIAMO. According to the Law No. 28/1984 coll. [1], these facilities were not proclaimed as "nuclear facilities". The only activities of the CAEC were in the field of uranium concentrate transport pursuant to its physical protection [2] and safeguards [3].

In the 90s by the resolution of the Government of the Czech and Slovak Federal Republic [4], the CAEC has been obliged as the state authority, to be responsible for control of uranium concentrate quantity, quality, security and safety of the storage facilities constructed and operating by DIAMO as state reserve storages. In all the above mentioned areas CAEC was performing regular inspection activities.

After the dividing of CSFR, by Czech Law No. 21 [5] the State Office for Nuclear Safety (SONS) has been created and from January 1, 1993 covering the state supervision on nuclear safety of nuclear facilities, performed previously by the CAEC.

SONS's responsibility are as follows:

a) state supervision on nuclear safety of the nuclear facilities [1], on management of radioactive wastes originated from nuclear facilities and management of the spent fuel,

b) state supervision on nuclear material including accounting for and control of [7],

c) state supervision on physical protection of the nuclear facilities and nuclear material [8].

Recently SONS s activities at uranium mining and milling facilities are focused on the sitting, construction and operation of the storage facilities of the uranium concentrate [4, 7, 8] and uranium concentrate transport [1, 7].

Wastes arising from the mining and milling of radioactive ores poses potential environmental and public health problems because of their radioactivity and chemical composition.

Present legislation concerning waste management is a mixture of previous federal and national regulations accepted by the Czech Republic in 1993.

The basic document for Waste Management is the Czechoslovak Law No. 238/1991 Coll. [9]. This law defines the basic terms and responsibilities of the state authorities and waste producers in waste management and defines penalties for different offences. It authorized government to issue more detailed regulations. This law applies also to the radioactive waste management unless special regulations specify otherwise.

The Law [9] defines that for management of radioactive wastes is to apply the Regulation of the former Czechoslovak Atomic Energy Commission No. 67/1987 Coll. [10], on Assurance of Nuclear Safety in Radioactive Waste Management and the Regulation of Czech Ministry of Health No. 59/1972 Coll. [11], on Protection of Health against Radiation.

The Regulation [10] gives obligatory procedures for sitting, design, construction, commissioning, operation, maintenance and decommissioning of nuclear facilities (nuclear power plants, research reactors, storages) or their parts that are intended for management of radioactive wastes. The definition of radioactive waste is slightly different as in the Regulation [11].

According to the Regulation No. 67/1987 Coll. [10], wastes are the unusable waste products and unusable objects which may contain radionuclides and which under conditions defined by special regulations may be introduced into the environment. On the other hand, radioactive wastes are unusable waste products and unusable objects which shall not for reasons of their high content of radionuclides or unremovable surface contamination be introduced into the environment. In Regulation [10],there are also given requirements not only for collection, treatment, conditioning, storage, transport and disposal of radioactive wastes, but also for the safety documentation. The documentation includes safety analyses, environmental impact assessment including risk analysis, cost benefit analysis and the consideration of economic and social aspects. On the basis of its evaluation, SONS is obliged to issue the decision according to the Law No. 28/1984 Coll. [1].

The Regulation [11] formulate the basic principles of radiation protection based on the ICRP and IAEA recommendations. It gives the legal definition of "radioactive waste" as a waste in solid, liquid or gaseous state formed during the application of radionuclides, in nuclear power plant operation or during mining and milling raw materials which contains radioactive material or are contaminated with them. According to this regulation the facilities are not allowed to dispose radioactive sources and wastes into the ground or to discharge them into the water or air without approval of the Hygiene Service Authorities. Discharges into surface waters must be approved by the Authorities of Water Inspection and into air by the State Technical Inspection of the Atmosphere, in agreement with the Health Authorities.

The Law No. 309/1991 Coll. [12], on Air Protection against Contaminating Materials specifies that the protection of atmosphere in relation to operation of nuclear facilities and their emissions of radionuclides is provided by special regulation.

The Law No. 17/1992 Coll.[13], on Environmental Protection requires for the licensing processes of the facilities including the nuclear and radioactive waste disposal ones the necessity of the environmental impact assessment including international discussions if necessary. Detailed requirements on the content of environmental impact assessment studies including nuclear and waste storage or disposal facilities are given in the Law of Czech Republic No. 244/1992 Coll.[14], on the Environmental Impact Assessment.

The requirements for waste treatment technology, waste storage and disposal facilities are given in the Regulation of the Government of the Czech Republic No. 513/1992 Coll. [15] on Details in the Waste Management. Special problems of radioactive wastes are referred to the above mentioned regulations [10,11].

The concentrations of contaminants in liquid effluents and surface waters have been set in the Regulation No. 171/1992 setting limits of permissible contamination in water. For the radioactive discharges it is referred the Regulation [11] and limits for effluents from uranium treatment technology. There are set limits of concentrations for U, Ra, Cs-137, Sr-90, H-3, gross alpha and beta activity in surface waters. The radioactive wastes are mentioned also in the Law No. 4/1988 Coll., on Protection and Use of Mineral Wealth, the Regulation No. 99/1992 Coll. [16], on Establishment, Operation, Ensurement and Liquidation of Facilities for Underground Waste Disposal, the Law No. 50/1976 on Regional Planning and Building Order, the Law No. 138/1973 Coll.,on Water Management, the Regulation No. 6/1977 Coll.,on the Protection of Quality of Surface Water, the Law No. 388/1991 on the State Fund for Environmental Protection and the Law No. 458/1992 Coll., on State Administration in Water Management. In accordance with the Provision of the former Federal Committee of Environment on Categorization and Waste Catalogue of August 1, 1991 the radioactive wastes are included into special or dangerous wastes in the group 7.

Under preparation of the new legislation related to nuclear fuel cycle it is expected that responsibilities of the various regulatory authorities in the radioactive management will be more precisely defined.

REFERENCES

[1] Czechoslovak Law No. 28/1984 dated March 22, 1984. on State Supervision on Nuclear Safety of Nuclear Facilities

[2] The Convention on the Physical Protection of Nuclear Material. Vienna, IAEA INFCIRC 274/Rev. 1 (May 1980)

[3] Agreement between the Czechoslovak Socialist Republic and the Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons.

[4] Resolution of the Government of the Czech and Slovak Federal Republic No. 894 dated December 17, 1990 on changes of the conception in uranium mining reduction in CSFR in connection on demand of the nuclear energy and report on inspection of the conditions for realization of uranium industry reduction programme for period 1990 to 2000.

[5] Law No. 21 of the Czech National Council dated December 21, 1992.

[6] Law No. 287, dated November 11, 1993 on activities of the State Office for Nuclear Safety.

[7] Regulation No. 28/1977 Coll.of the CAEC on accounting for and control of nuclear material. April 12, 1977.

[8] Regulation No. 100/1989 Coll. of the Czechoslovak Atomic Energy Commission on Physical Protection of Nuclear Facilities and Nuclear Material. September 5, 1989.

[9] Czechoslovak Law No. 238 Coll., on Wastes, dated May 22, 1992

[10] Regulation of the Czechoslovak Atomic Energy Commission No. 67/1987 Coll., on Assurance of Nuclear Safety in Radioactive Waste Management, dated June 30, 1987.

[11] Regulation No. 59/1972 Coll. of Czech Ministry of Health, on Protection of Health against Ionizing Radiation dated June 30, 1972.

[12] Law No. 309/1991 Coll., on Air Protection against Contaminating Materials, dated July 9, 1991.

[13] Czechoslovak Law No.17/1991 Coll., on Environmental Protection, dated December 12, 1991.

[14] Czech Law No. 244/1992 Coll., on Environmental Impact Assessment, dated April 15, 1992.
[15] Regulation of the Government of the Czech Republic No. 513/1992 Coll., on Details in the Waste Management, dated September 23, 1992.
[16] Regulation No. 99/1992 Coll. on Establishment, Operation, Ensurement and Liquidation of Facilities for Underground Waste Disposal, dated February 20, 1992.

DECOMMISSIONING AND REHABILITATION OF URANIUM MINES AND MILLS IN GERMANY

(Abstract)

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With the reunification of the two Germanies in 1990 the Federal Republic of Germany became one of the biggest uranium producing countries in the world. A post-war production of 220,000 metric tonnes of uranium places in Germany in the front line of the uranium producing countries, exceeding by far the post-war production of Australia, South Africa and the Soviet Union. Unlike in other producer countries all mining operations were carried out in a relatively small mining district, approximately 150 km long and 50 km wide, in the southern part of eastern Germany. Especially in the first years of uranium production the then Soviet-owned WISMUT Company carried out mining practically without considering the damage to the environment or humans. The result of 45 years of uranium mining in the states of Saxonia and Thuringia are many square kilometres of contaminated areas and facilities; they were used for a certain period of time for different purposes like intermediate storage, transport, mining and milling of ore as well as the deposition of waste rock and tailings. All these problematic areas are not situated in the remote loneliness of northern territories or deserts like in Canada and Australia, but instead in one of the most densely populated areas of Germany. Since uranium mining is far from being profitable by western standards, the German Federal Government and the Soviet Government came to an agreement to stop mining by the end of 1990. In 1991 a huge decommissioning and rehabilitation programme was initiated with the aim of minimizing ecological hazards and realizing the fast closedown of the expensive underground operations. As in all centrally planned economies the WISMUT Company had not built up any financial reserves. It is now the Federal Government which enables the government-owned WISMUT GmbH by enormous funding of approximately 13 billion German Marks over a project period of 10 to 15 years to carry out the decommissioning and rehabilitation programme. The government sees to it that an optimum is achieved under ecological, financial and social aspects; i.e. the aim of the decommissioning and rehabilitation programmes is to re-establish in the involved areas widely intact ecological conditions. At the same time the economic, industrial and social structures must be kept in a state of balance. For decommissioning and rehabilitation the best available know-how and the international market is integrated. Thereby expertise is concentrated in order to achieve the optimum between ecological benefit and financial input. In the presentation further information will be given on the legal, financial and organizational aspects of the German programme as well as the political issues.

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DECOMMISSIONING OF US CONVENTIONAL URANIUM PRODUCTION CENTERS

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Abstract

The Energy Information Administration (EIA) is a quasi-independent Organization within the U.S. Department of Energy (DOE), responsible for collecting, analysing, and disseminating information on energy including the U.S. uranium industry and nuclear power generation. The EIA is also actively involved in assisting the DOE Office of Environmental Restoration and Waste Management to implement the reimbursement of mill tailings remediation costs in compliance with Title X of the Energy Policy Act of 1992. As one of our recent projects, we examined the decommissioning efforts of conventional uranium production centers. This paper summarizes that work. For conventional uranium production centers, decommissioning involves decontaminating and dismantling the mill itself, reclaiming the tailings pile(s), restoring groundwater to acceptable conditions, and long term monitoring of the site. In examining these Issues, this paper: (1) presents a brief history of the development of the regulations that govern the industry, (2) describes the decommissioning process for conventional uranium production centers and (3) compares aggregated decommissioning cost data for six selected conventional uranium mills, based on filings with the U.S. Nuclear Regulatory Commission.

1. BACKGROUND

1.1. Regulatory development

To start with, the Atomic Energy Act of 1946 created the Atomic Energy Commission and gave the AEC regulatory authority over radioactive materials. Then in 1964, to promote a gradual commercialization, Private Ownership of Special Nuclear Materials Act was enacted (see Fig. 2).

Pursuant to the Energy Reorganization Act of 1974, the AEC was divided into two separate agencies in 1975 — the Energy Research and Development Administration (which later was incorporated into the U.S. Department of Energy) and the Nuclear Regulatory Commission (NRC). Primary responsibility for regulating uranium processing and decommissioning activities was transferred from the AEC to the NRC, which exercises authority over the licensing process for uranium production facilities and regulations on decommissioning.

Like the AEC before it, the NRC did not interpret its authority as extending to uranium mines. The enforcement of most mining regulations is carried out by the individual States. Open pit mines may have to be backfilled, and may have to be recontoured to a more natural shape for revegetation. Other than a mandatory requirement to close shafts and mine openings, underground uranium mines generally have few reclamation requirements.

1.2. Current regulations of uranium recovery facilities

To put our industry into perspective for you, uranium production in the United States fell from 44 million pounds of U_3O_8 in 1980 to less than 6 million pounds in 1992. As a result, a number of uranium-producing facilities were permanently closed. Of the 26 licensed conventional uranium mills in the United States, none are operational, six are on standby, two have been decommissioned, and 18 are in various stages of decommissioning. To date, these mills have produced more than 200 million dry short tons of tailings. The Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) is the basis for present-day control of uranium mill sites. It stipulates that the EPA set environmental standards and guidelines and that each NRC license contains provisions regarding decontamination, decommissioning, and reclamation of the licensed facility.

A licensee must present a plan for site reclamation to the NRC for approval. If the NRC approves the plan and the cost estimate, the licensee must then post a surety bond to assure that funds will be available to reclaim the site if the licensee is unable to complete the task.

After satisfactory completion of decommissioning by the licensee, title to the site and the uranium tailings passes to the DOE, or to the appropriate State which is responsible for long term monitoring and care of the site.

2. THE DECOMMISSIONING PROCESS

2.1. Mill decontamination and dismantling

The mill decontamination and dismantling activities consist of the following steps:

1. Cleanup and decontamination of equipment and buildings, using spraying, steam cleaning, or other methods, as needed. Also involved in this operation is the disposal of cleanup fluids in evaporation ponds.

2. Removal of equipment from the buildings during the cleanup process. Equipment is segregated into the following categories:

   a) that which is potentially salable for unrestricted use,

   b) that which is contaminated but potentially salable to other uranium operations, and

   c) that which is disposable. The sales of salvaged equipment are unlikely to be significant, considering the limited potential market, the costs involved for seller and buyer, and the potential liabilities.

3. Dismantling of buildings and foundation structures. Cutting, crushing and flattening of equipment, pipes, tanks, and structural material for ease of handling.

4. Burying debris, usually in the tailings pile, some distance from the edge of the pile. The debris is placed in the pile in layers, with dirt compacted in and around it. Since a tailings pile must have dried and compacted sufficiently to support heavy equipment, such piles might not be accessible for disposal of mill debris for some years.

5. Cleanup of the mill site. Contaminated debris and soil are removed, as are roads and parking lots.
6. Ripping, regrading, resoiling, liming, fertilizing, and reseeding as necessary to establish vegetation. To enhance its long term survival, the types of vegetation selected should be indigenous to the area.

2.2. Tailings piles reclamation

Groundwater contamination comes mostly from the tailings pile. Depending on the siting and design of the pile, the efforts to clean up groundwater to acceptable levels may be extensive at some sites.

The steps involved in cleaning up the tailings piles are as follows:

1. The edges of the piles are reshaped to minimize erosion hazards from surface water runoff.

2. The slopes and edges of the piles are covered with radon barrier material and rock or other cover (usually a clay or silty material).

3. Drainage in the vicinity is redirected away from the piles. Consideration must be given to the maximum possible magnitude of flood water over the design life of the tailings pile, which is at least 200 years.

4. The piles are allowed to settle and dehydrate. This may take years if the pile is slow In releasing moisture. Generally, pools of liquid on the tailings piles receive additional water from rainfall. The slimy, clay-like nature of the fine materials from the milling process and the lack of capillary action inhibits moisture release and movement to the drying surface. Piles placed on porous material without sealing materials will drain through the bottom. Piles with synthetic or clay liners at the base will depend either on drainage systems built into the pile or on evaporation. To hasten drying, additional moisture should be kept off the pile. Settlement of tailings must be monitored by establishing survey monuments on the pile and checking their movement, both vertically and laterally.

5. The entire pile is covered with a radon barrier. The material for this cover is usually the same as that used to cover the edges and slopes of the piles, and to verify its suitability, it must be tested for such characteristics as acidity and radioactivity associated with disposal of heavy metal contaminants. The thickness of the cover (from 6 inches to more than several feet) required to meet standards varies with the nature of the tailings pile and with the material available for cover. This barrier also serves to keep additional moisture off the pile, thus avoiding subsequent drainage into groundwater.

6. The final pile cover is a protection against erosion and should be deferred until the pile settlement is almost complete. The erosion cover may be of soil if revegetation is planned, or of rock if revegetation is not feasible. The site must be monitored for erosion of the soil and growth of the vegetation.

7. The restricted part of the site is enclosed with a fence.

8. A portion of the area of the tailings pile may be needed for final disposal of wastes at the site, particularly those wastes that may continue to accumulate from groundwater cleanup.
9. The site is monitored to ensure that all aspects of the design and construction programs have worked as expected, that all standards have been met, and that no unexpected changes have occurred at the site.

2.3. Groundwater restoration

The general approach to controlling groundwater problems during the operating life of the mill is to restrict the generation of additional contaminated groundwater, to prevent the movement of such water from the site, and to collect it (as necessary) for treating and recycling.

The process comprises the following seven steps:

1. Wells and piping systems are established in and around the site area to collect the groundwater and to monitor its quality.

2. Cutoff ditches and drains to bedrock may be placed where drainage from the site occurs, such as at the base of the tailings pile.

3. Input and collection wells may be built to prevent groundwater from moving through geological formations and off the site.

4. Limiting the amount of surface water entering the site may be necessary to reduce groundwater flows.

5. Interception of groundwater entering the site by use of wells or underground openings may be used to reduce potential contamination.

6. Lined evaporation ponds may be constructed for disposal of collected contaminated groundwater. New ponds may be needed to minimize additional contamination. Because the solid wastes from the ponds will be disposed of in the tailings pile or at some other final disposal site, a final disposal location must be kept available until the last phases of the project.

7. Groundwater must be collected and monitored, and, if necessary, treated until all standards are met.

3. ANALYSIS OF DECOMMISSIONING COST DATA FOR SELECTED MILLS

Cost analysis data were obtained from the licensees' filings with the NRC. To simplify the analysis, costs are aggregated into the two following basic categories: (1) mill decommissioning and site reclamation, (2) reclamation of tailings piles, and (3) groundwater restoration and (4) other costs, which include 15 percent contingency fee, and 10 percent allowance for overhead, profit, and long term surveillance and control of the reclaimed areas.

For each of the six conventional operations analyzed, mill dismantling costs accounted for less than 12 percent of the total decommissioning costs. At Bear Creek, mill dismantling costs accounted for about 5 percent of total decommissioning costs — the smallest percentage of any of the projects. Sweetwater has the highest percentage for dismantling costs (11.5 percent), because its relatively short operational life (from 1980 through 1983) limited the other costs. However, when costs are compared in dollars, the Sweetwater plant's costs are the lowest.

For five of the six conventional mills studied, tailings reclamation costs represented the largest factor in decommissioning costs. For three of the mills, these costs represented more than half of the total decommissioning costs: Ambrosia Lake, 64 percent, Sweetwater, 55 percent and Bear Creek 52 percent. Ambrosia Lake was the largest of the six operations analysed and generated the most mill tailings. Although the Grants plant accounted for nearly five times as much tonnage of mill tailings as the Bear Creek plant, its costs for tailings reclamation were less because of other favorable factors that influence reclamation costs, such as topography, geographic location, subsurface lithologic conditions, and tailings pile design.

Groundwater restoration costs are normally less than tailings reclamation costs at a conventional mill, but they can be substantial. At the Grants mill, groundwater restoration costs accounted for 43 percent of the total decommissioning costs. This was the only conventional mill (of the six studied) that had higher costs for groundwater restoration than for tailings reclamation because Grants mill tailings encountered a higher level of groundwater contamination in contrast to the other mill tailings, due to problems with seepage by water runoff.

Decommissioning costs of uranium mills vary substantially by site, and caution should be used when calculating or interpreting "average" costs. For example, groundwater reclamation costs range from $300,000 to $9.7 million. Recently built mill sites incorporate better design features (such as liners to the tailings ponds), which reduce decommissioning costs.

The tailings reclamation costs averaged $32,000 per acre of tailings, with a range of $9,000 to $57,000 per acre. The wide range reflects differences in the design and configuration of the tailings piles and the reclamation measures required. The total costs of the tailings reclamation, Including contingencies and allowances, averaged $1.13 per ton of tailings and ranged from $0.57 to $2.62 per ton.

4. IMPACT OF DECOMMISSIONING COSTS ON URANIUM PRICE

From the previous discussion it can be seen that decommissioning conventional uranium production centers can be costly. To put these costs into perspective it is useful to examine the relationship between the costs of decommissioning the production facilities examined here and the price of uranium.

Based on several assumptions, the average total decommissioning cost per pound of U_3O_8 is $0.39, of which $0.18 is for tailings reclamation. By comparison, the average price of uranium delivered by domestic producers in 1992 to domestic utilities was at an historic low of $13.45 per pound U_3O_8. The average decommissioning costs then represent 2.9 percent (ranging from 1.5 percent to 6.9 percent) of the average price of U_3O_8. Thus, if these costs are representative of the costs of a new plant, they would have a small impact on the overall price of uranium, particularly if the price of uranium rises above its current historic low.

5. SUMMARY

Other costs for such a rejuvenation would likely be far higher than the costs associated with the decommissioning phase alone. With the current regulatory system and standards for decommissioning, the costs can be factored into the planning of future operations and amortized over the life of the mill, and thus should not hamper future development of production facilities.

Decommissioning entails considerable costs for the industry. The amount of surety bonds in effect, which covers costs for third parties to do the decommissioning for the 26 existing conventional mills, is $237 million. Future operations would expect a lower rate of decommissioning costs through improved tailings pile design and groundwater restoration technology and practice. The decommissioning costs are normally amortized over the life of the operation and added into projected sales prices that would support developing a new plant. Therefore, decommissioning requirements would have some influence on prices, but they would not have a significant impact on future U.S. uranium production.

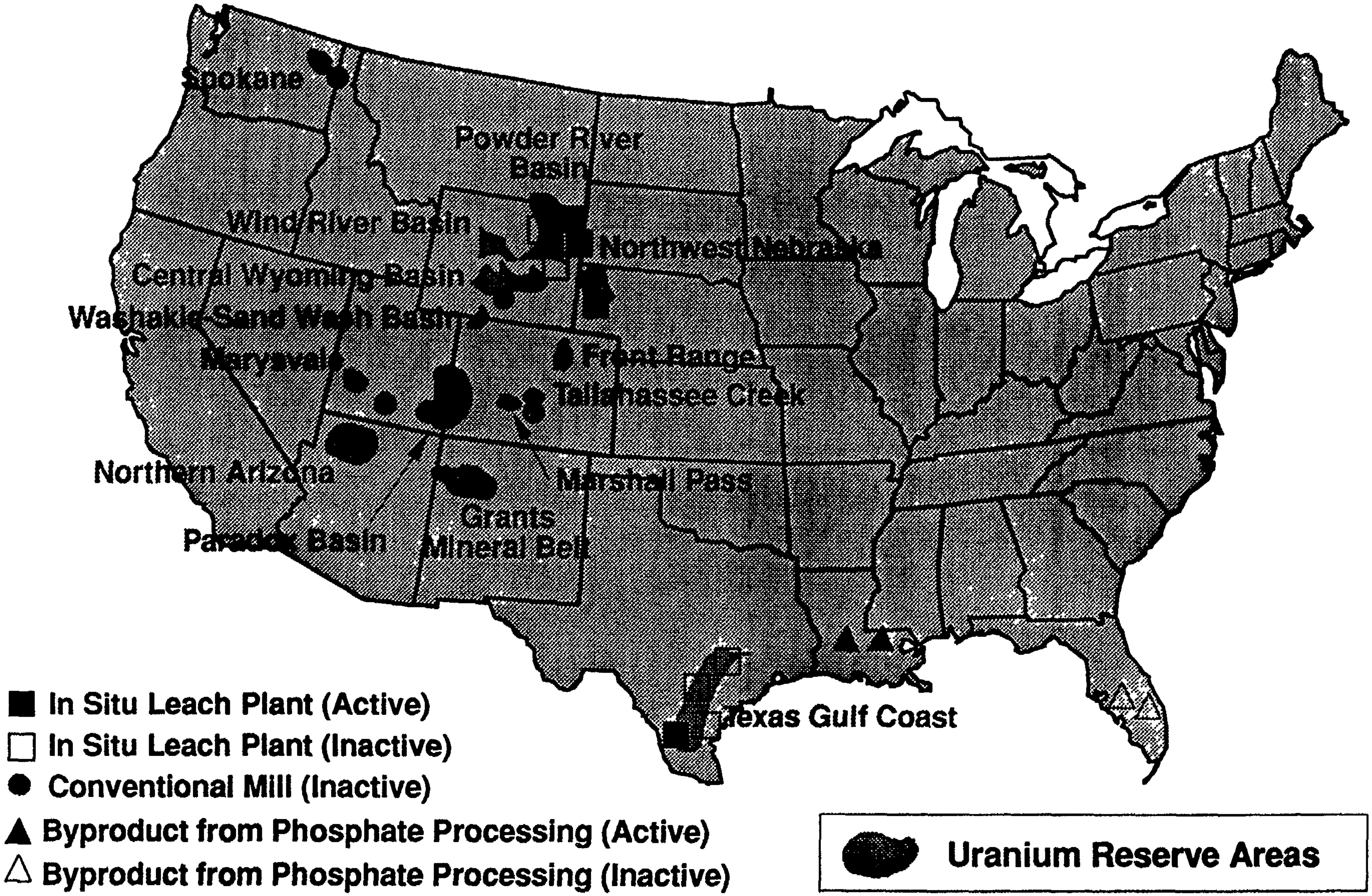

FIG. 1. Major uranium reserve areas and status of mills and plants, December 31, 1993.

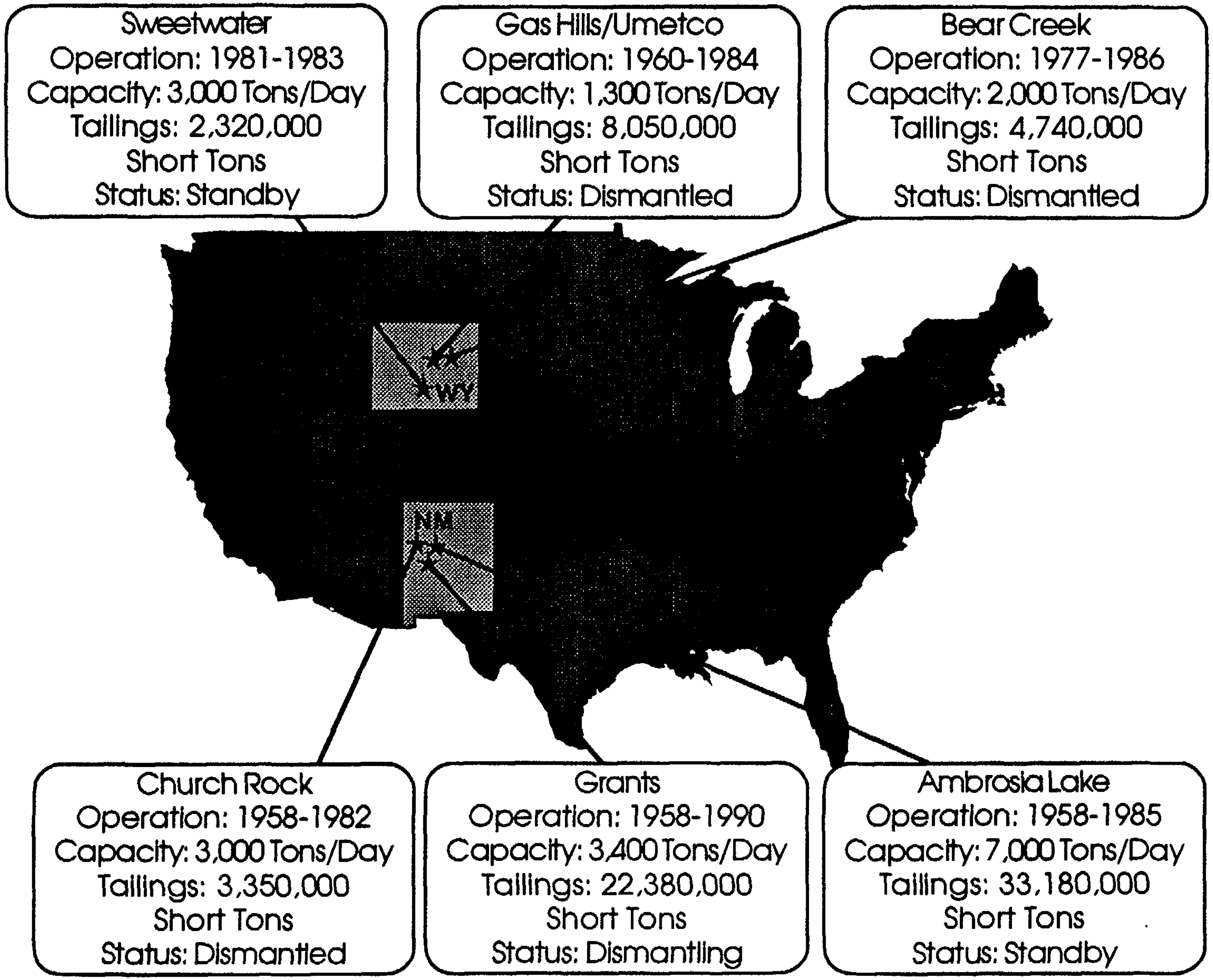

FIG. 2. Selected production centers.

- **1946 - Atomic Energy Act**
- **1964 - Private Ownership of Special Nuclear Materials Act**
- **1974 - Energy Reorganization Act**
- **1978 - Uranium Mill Tailings Radiation Control Act (UMTRCA)**
- **1992 - The Energy Policy Act - Title X, Remedial Action and Uranium Revitalization**

FIG. 3. Regulatory Development.

	Ambrosia Lake	Bear Creek	Church Rock	Gas Hills/ UMETCO	Grants	Sweet-water	Total
Tailings							
(Thousand Tons)	33,180	4,470	3,527	8,047	22,377	2,315	74,186
(Acres)	328	150	100	146	215	300	1,239
Decommissioning Costs							
Mill Dismantlement Costs (Thousand Dollars)	1,391	610	689	968	1,607	564	5,829
Tailings Reclamation Costs (Thousand Dollars)	12,129	6,437	3,472	8,258	6,405	2,697	39,398
Groundwater Restoration Costs (Thousand Dollars)	1,149	2,486	2,118	3,629	9,688	267	19,377
Other Costs[a] (Thousand Dollars)	4,170	2,886	2,073	3,717	4,928	1,385	19,159
Total Decommissioning Costs (Thousand Dollars)	18,839	12,419	8,352	16,572	22,628	4,913	83,723

(1991 Dollars)

a Includes contingency/overhead and long-term care.
b Weighted average.
Source: Company filings with U.S. Nuclear Regualtory Commission.

FIG. 4. Decommissioning costs for selected conventional production centers.

- **Decontamination of equipment and buildings**
- **Removal of equipment**
- **Dismantling of buildings and foundation structures**
- **Burying debris (usually in the tailings pile)**
- **Cleanup of the mill site**
- **Resoiling and vegetation of the surface area**

FIG. 5. Mill decontamination and dismantling.

- **Minimize erosion of piles**
- **Radon barrier covering on slopes**
- **Redirecting drainage away from piles**
- **Piles allowed to settle and dehydrate**
- **Pile covered with radon barrier**
- **Final pile cover for erosion protection**
- **Site enclosed with fence**
- **Provide space for final disposal of site wastes**
- **Site monitoring**

FIG. 6. Tailings pile reclamation.

- Collecting and monitoring groundwater
- Diverting drainage from bedrock seepage
- Preventing groundwater from moving off site
- Limiting surface water entering the site
- Intercepting groundwater entering the site
- Collecting contaminated groundwater in lined evaporation ponds

FIG. 7. Groundwater restauration.

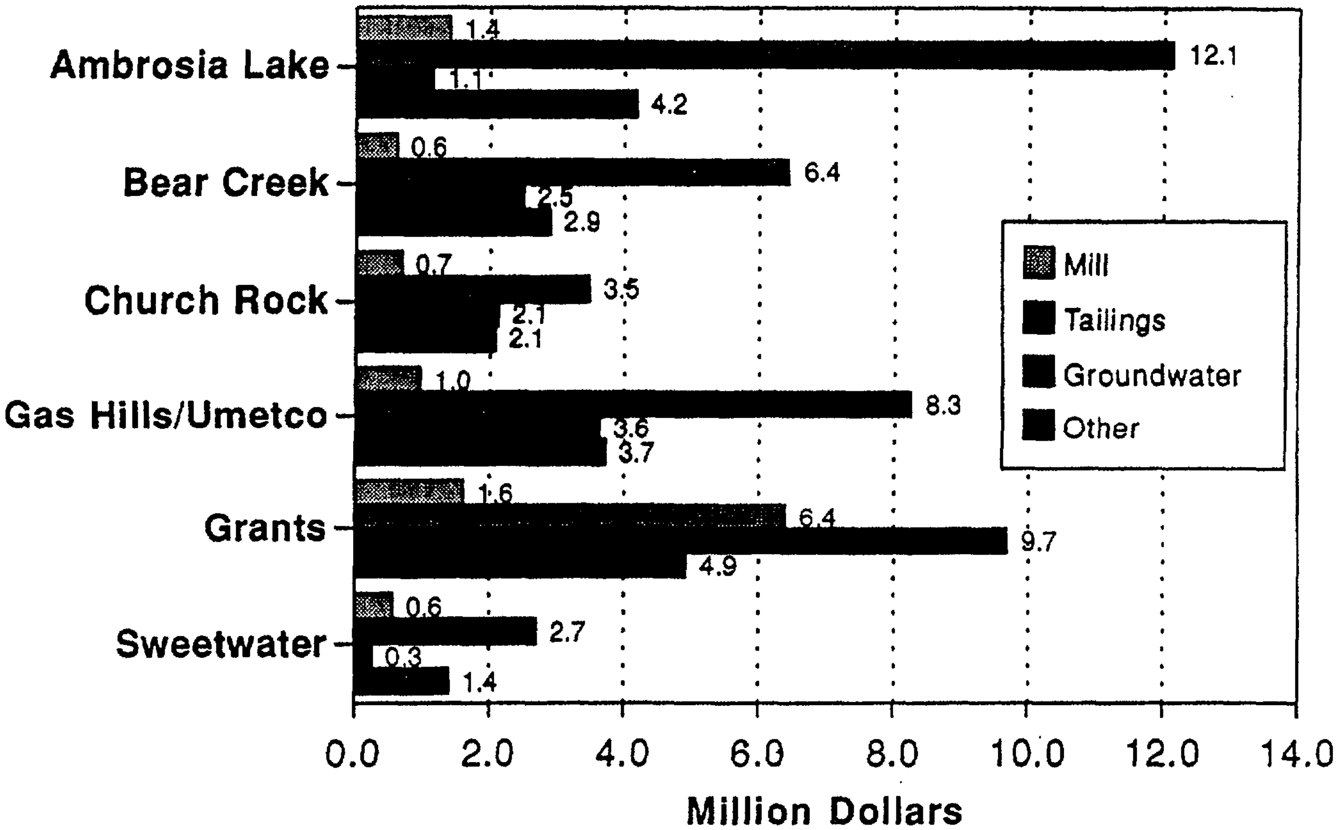

FIG. 8. Estimated costs by major components.

	Production** (million lbs U3O8)	Tailings Reclamation Costs ($/lb U3O8)	Other*** Costs ($/lb U3O8)	Total Decommissioning Costs ($/lb U3O8)
Ambrosia Lake	94.1	0.13	0.16	0.20
Bear Creek	13.4	0.48	0.71	0.93
Church Rock	10.3	0.34	0.61	0.81
Gas Hills/Umetco	26.2	0.32	0.49	0.63
Grants	62.7	0.10	0.28	0.36
Sweetwater	6.8	0.40	0.52	0.72

Weighted average
* Production--derived from estimates of 95% recovery & 15% av. U3O8 grade
** Includes dismantling, restoration & monitoring

FIG. 9. Decommissioning costs per pound of U_3O_8 for selected production centers.

AUSTRALIAN EXPERIENCE IN THE REHABILITATION OF URANIUM MINES AND MILLS

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Abstract

Australia has a long history of uranium mining. In the early days, little attention was given to environmental matters and considerable pollution occurred, particularly at the Rum Jungle site in the Northern Territory. In the 1970's, there was increased community concern about environmental matters which was reflected in the passing of the Environment Protection Act. This Act requires all mining companies to have plans for closure, decommissioning and rehabilitation approved before mine development is commenced. In the early 1980s, the Federal Government provided funds for the rehabilitation of the Rum Jungle site. Since then, two other major uranium mining and milling facilities have also undergone rehabilitation. Currently there are two large uranium mining operations in Australia These mines were developed and operate under strict regulatory control which requires the implementation of best practicable technology to minimize environmental impact. Integration of rehabilitation/decommissioning requirements into operating plans is an essential feature of the long term management of these projects. This paper describes Australia's experience in the decommissioning of uranium mining operations. Careful planning of tailings and water management during the operational phase is essential to simplify and reduce the cost of closure, while still achieving environmental standards.

1. INTRODUCTION

The search for uranium in Australia began in earnest in 1944, when its strategic importance became known. Between 1954 and 1971, about 10 000 tonnes of yellow cake were produced at five locations. Most of the production came from the mines at Rum Jungle in the Northern Territory and Mary Kathleen in Queensland.

The first uranium mining operations in Australia were typical of overseas practice at the time. Environmental problems were given low priority and pollution control measures were rudimentary and unacceptable by today's standards. Tailings dams were poorly designed and, at Rum Jungle, oxidation of sulphides in waste heaps led to destruction of vegetation and heavy metal pollution in a nearby river.

The demand for uranium increased in the late 1960s and resulted in considerable exploration activity. By 1974, drilling had confirmed the Alligator Rivers region of the Northern Territory as one of the world's major uranium provinces. Significant orebodies were also discovered in South Australia, Western Australia and several locations in Northern Queensland.

The new discoveries occurred at a time of increased environmental awareness. In 1974, the Australian Parliament passed the Environment Protection (Impact of Proposals) Act. One of the first projects to fall under the scrutiny of the Act was the proposal by Ranger Uranium Mines Pty Ltd to construct a mine and mill at Jabiru in the Northern Territory. Following a public inquiry, the government decided in 1977 to proceed with developments, subject to strict environmental safeguards and agreement with the traditional aboriginal landowners. Two further uranium projects subsequently came to fruition, the high-grade (2% U) Nabarlek project in the Northern Territory and the extensive Olympic Dam uranium-copper-silver-gold project in South Australia.

Ansto and its predecessor, the Australian Atomic Energy Commission (AAEC), have been involved in the uranium mining industry for over 40 years. In recent years, Ansto has been involved in the restoration of the old mining sites, as well as working with the current producers to ensure that operations are carried out in keeping with strict environmental standards. Ansto is also providing advice on the restoration of the uranium mines of Wismut GmbH in Germany.

This paper describes Australia's experience in the decommissioning of uranium mining operations, with particular emphasis on the integration of rehabilitation/decommissioning requirements into operating plans. The paper also discusses, in general, site specific factors and tailings storage/disposal options, which must be considered in the planning stages of a project if successful decommissioning is to be achieved.

2. PLANNING FOR DECOMMISSIONING

Australian experience has shown that planning and proper waste management during the operational phase are the key to cost effective and environmentally acceptable decommissioning of a uranium mine and mill. In this context, a thorough understanding of site specific factors and their impact on waste management options is essential. The implications of these options on eventual decommissioning/closure requirements must also be considered.

2.1. Site specific factors

Many factors affect the environmental impact and decommissioning of a uranium mining operation. A list of some of these factors is given below in approximate order ranging from those that are site-specific to those that are elective waste management decisions [Levins and Davy 1983]:

No Control

- Mineralogy of the host rock, particularly the presence of pyrite or toxic elements
- Geology, hydrogeology and topography of region
- Climate, particularly annual rainfall and evaporation
- Alternative land use
- Proximity to population
- Pollutant paths

Limited Control

- Ore grade
- Waste rock to ore ratio
- Mining method (e.g. open cut, underground or in-situ leaching)
- Mill flowsheet
- Tailings impoundment type (e.g. ring dyke, valley dam, excavated pit)
- Treatment of liquid wastes (e.g. neutralization, barium chloride addition)

	–	Tailings emplacement method (e.g. dilute or thickened slurry, filter
Elective Decision	–	Final tailings containment (above or below grade, cover thickness)

Waste management practice should aim to exploit any advantages that a specific site may offer and counter any special problems.

2.2. Waste management options

2.2.1. Water Management

Climatic factors are of paramount importance to water management. This is clearly illustrated by comparing average annual precipitation and evaporation in four or the world's major uranium producing areas.

	Precipitation	Evaporation	Net Evaporation
New Mexico, USA	3100 mm	1500 mm	1190 mm
Alligator Rivers Region, Australia	1400 mm	2200 mm	800 mm
Elliot Lake, Canada	790 mm	500 mm	-290 mm
Thuringia, Saxony	700 mm	4500 mm	-250 mm

In semi-arid climates, excess water can be evaporated, but in the monsoonal climate of northern Australia, rainfall is quite variable and, in a wet year, rainfall may exceed evaporation. Water management is still based on evaporation, but adequate storage must be provided to cope with 2-3 successive wet years. At Elliot Lake, process waters must be released to lakes and rivers after treatment.

Water management schemes, where possible, should consider the following:

- areas of the site likely to be contaminated should be cut off from clean catchment areas;
- run-off from catchments (e.g. ore and waste heaps, mill areas) should be collected and segregated on the basis of likely contamination;
- if climatic factors are favourable, evaporation ponds should be constructed to dispose of excess water;
- mine water should be considered as a source of make-up water for the mill; and
- the feasibility of reusing tailings dam water in the mill should be investigated. Recycling of neutralized tailings water can reduce make-up requirements to 0.6–0.9 t water t^{-1} ore.

2.2.2. Tailings Management

2.2.2.1. Impoundment systems

Site–specific factors, particularly terrain, influence the selection of impoundment type. Examples are given below [Levins and Davy 1983]:

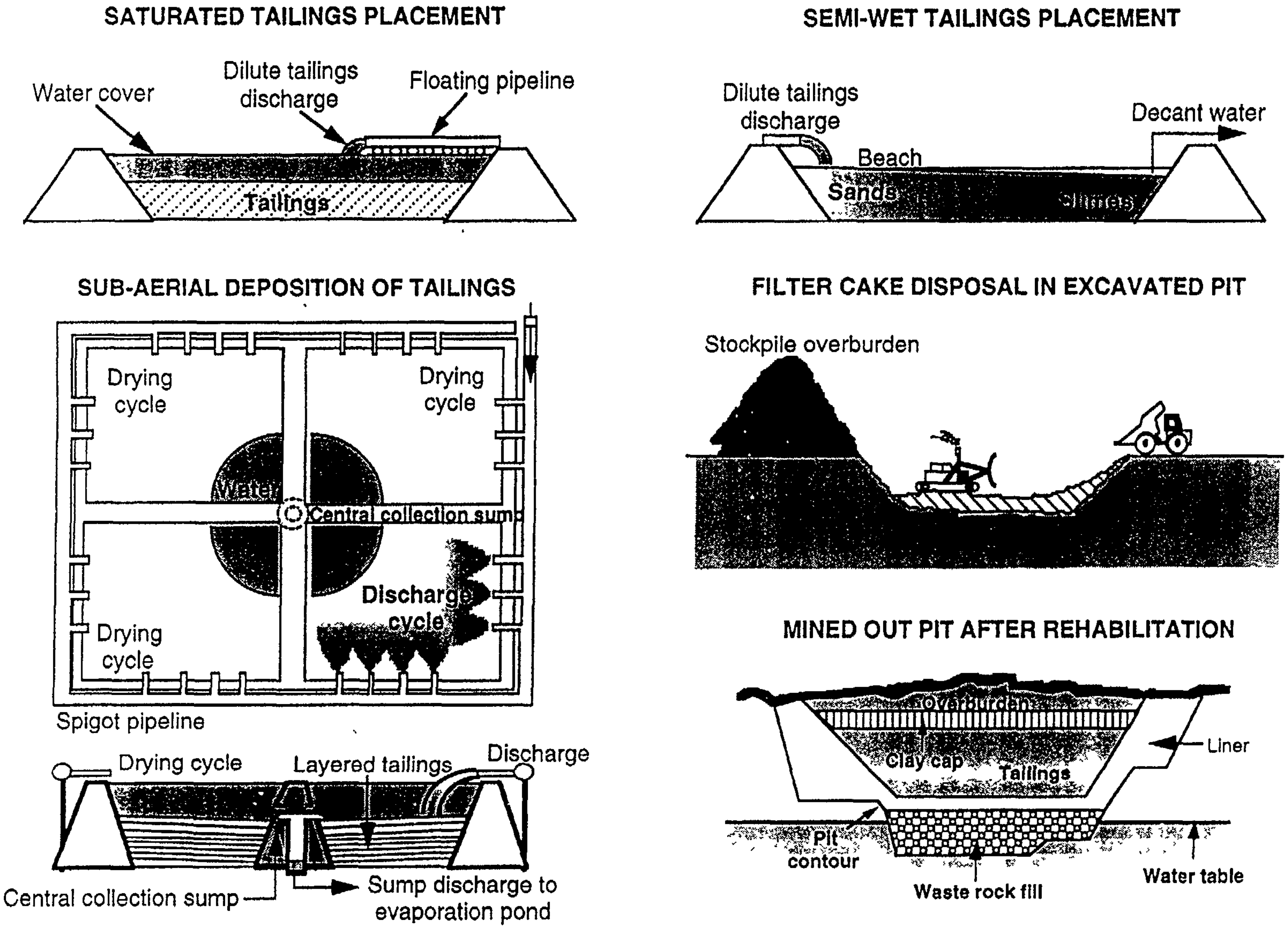


FIG. 1. Methods of tailings deposition.

- Ring dyke impoundments are constructed on flat terrain. They are designed similar to water storage dams and are usually constructed above the water table away from natural watercourses.

- Valley impoundment is only an option when a natural basin is close to the mill. Visual impact is low, but there is high potential for water erosion and pollutant transport. Valley impoundments usually have a large catchment area

- Backfilling of underground mines is attractive, but because of structural limitations, only the sands fraction can be used.

- Specifically excavated pits and trenches have greater flexibility and a high level of physical containment and rehabilitation can be undertaken as mining proceeds.

2.2.2.2. Methods of tailings deposition

The case histories presented later in this paper will show that the method of tailings deposition can have a significant effect on decommissioning. The five emplacement methods described below are depicted in Fig. 1. Four of these methods have been used in Australia.

Conventionally, tailings are pumped to the impoundment structure at a slurry density of 25-50 wt% solids. At some sites a water cover is maintained over the tailings to reduce radon emanation and prevent wind erosion. The tailings are discharged below the water surface from a floating pipeline. This approach maximizes evaporation, but produces a low settled density, particularly if the tailings are neutralized. The potential for seepage is also greatest with this method, hence neutralization is often a prerequisite.

Another variation is to discharge the tailings from the periphery of the impoundment area. A sloping beach of coarse material is then formed near the discharge point. Slimes are carried further and eventually settled beneath water that accumulates at the other end of the impoundment. Segregation of sand and slimes can be avoided if the tailings are thickened to about 60 wt% solids. Settled densities should be higher than those obtained with dilute tailings slurries.

Sub-aerial deposition of tailings involves intermittent discharge of the slurry onto a partially dried out beach. A layer, from 75–150 mm in thickness, is deposited and then the discharge is moved to another point. Free water drains from the tailings. Natural drying of the beach areas draws pore water to the surface and consolidates the tailings to a high density and a low permeability.

If tailings are filtered rather than thickened, the moist filter cake can be immediately consolidated to a high density by bulldozers. Seepage is minimized because the filter cake contains little pore water. This method of disposal may not be suitable for tailings with a high clay content because the filter cake is sticky and retains more water.

All tailings storage areas and evaporation ponds require control of seepage. This begins with site selection and preparation. The impoundment should be excavated to unweathered rock and all faults sealed by grouting. Clay or plastic liners are frequently used for the floor and embankment walls. Modern impoundment structures should also have drainage systems to collect seepage and return it to the tailings dam.

3. SITE SPECIFIC FACTORS IN AUSTRALIA

3.1. Regional environmental factors

The uranium deposits in Australia are located in widely different climates, ranging from monsoonal conditions in the Alligator Rivers region to semi-arid conditions in the inland. In the wet climates, waterborne pathways dominate and the potential for environmental degradation is greater. In dry climates, radon emanation and dust dispersion are more important considerations.

The Alligator Rivers region lies partly within Kakadu National Park, a world heritage area of great natural beauty. The annual rainfall in the region averages 1350 mm while evaporation is about 2200 mm. The climate is characterized by short-duration, high intensity rain storms in the wet season when the lowlands are traversed by meandering creeks and the lowest parts of the plains become vast lakes. As the dry season progresses, water quality deteriorates, imposing stresses on aquatic organisms through high temperatures, low oxygen levels and high concentrations of potentially toxic metals. These factors make the biota very sensitive to added metal values.

3.2. Ore processing flowsheets

With the exception of the underground mine at Olympic Dam, all Australian uranium ores have been mined by open cut methods. After mining, the ores are typically crushed and ground to below 50% -75 μm and leached in sulphuric acid at 40-60°C under oxidizing conditions. The uranium bearing liquor is separated from the tailing by counter-current decantation. The uranium is recovered by solvent extraction (ion exchange was used in the early plants) and precipitated with an alkaline reagent, most commonly ammonia. The yellow cake product is produced by calcining at 800°C.

3.3. Rehabilitation experience

Australia has a wide range of rehabilitation experiences ranging from remedial action after mine closure to on-going rehabilitation of operating mines. Because of site specific factors and regulatory requirements, varied water and tailings management schemes have been adopted. Experience has shown that changes to these schemes are often necessary if original rehabilitation goals are to be achieved.

Rehabilitation/decommissioning experience at five Australian uranium mills are described in the following sections.

4. REMEDIATION AT RUM JUNGLE

Rum Jungle is an abandoned uranium-copper open cut mining operation located in the tropical north of Australia, about 85 km south of Darwin. Mining was carried out between 1954 and 1964 and operations ceased in 1971. When it was abandoned, the main features of the site were (see Fig. 2):

- three waste rock dumps containing 10 Mt waste rock and covering an area of 51 ha;
- three water filled open cuts of total area 22 ha;
- a tailings disposal area containing 0.6 Mt tails over 31 ha; and
- copper heap leach pile containing 0.3 Mt ore over 2 ha.

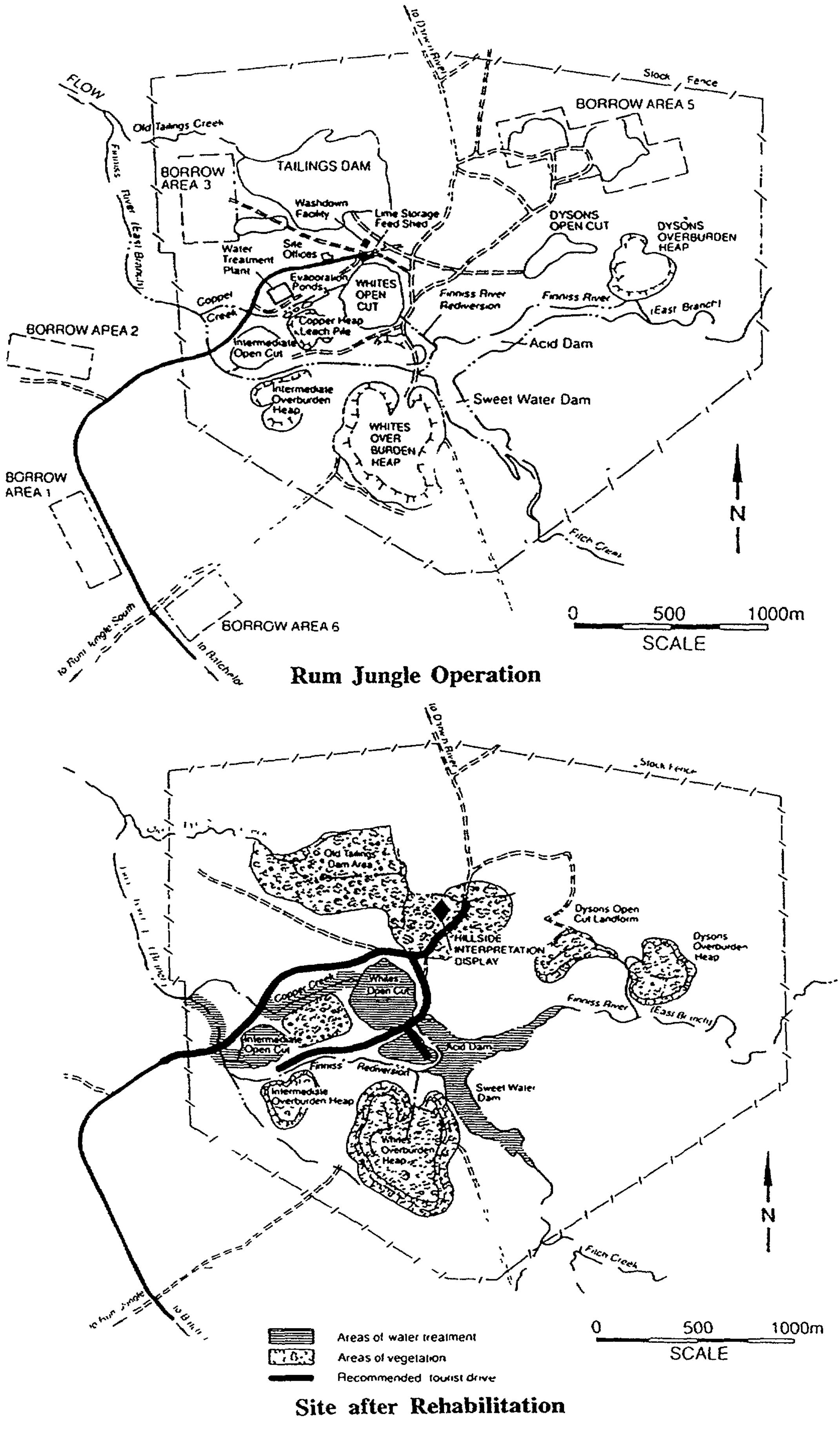


FIG. 2. Rum Jungle before and after rehabilitation.

Ore for treatment at Rum Jungle was extracted from five open cut mines. Ore was processed by acid leaching to recover 3 500 t U_3O_8 and 20 000 t of copper concentrate. Ore grade was 0.23–0.35% U_3O_8.

Mining at Rum Jungle was carried out under the criteria of the time which gave little consideration to environmental concerns. Towards the end of mining operations, it was apparent that effluent from the treatment plant and leachate from the mine waste dumps were having a serious impact on the flora of the mine site and, more importantly, on the aquatic life in the East Branch of the Finniss River which flows through the mine site. In the early 1970s the East Branch of the river was biologically dead from the mine site to its confluence with the main branch of the Finniss River, 12 km downstream of the mine site.

The major pollutants in the river were copper, manganese, zinc and sulphate arising from acid mine drainage arising from the pyritic ores associated with uranium in the ore and overburden (pyrite content was about 5%). The impact of uranium and its daughters was of minor concern compared with the impact of heavy metals. The waste rock dumps were the main source of pollution, contributing about 85% of the copper load in the East Branch, followed by the open cuts.

In 1977 an initial cleanup was carried out by the Federal Government. This involved removal of debris associated with mining and milling activities and was aimed at improving safety of the site rather than reducing the generation of pollutants on site. In 1983, the Government funded a project to rehabilitate the mine site at cost of about AUD$20 million. The objectives of the rehabilitation project were to reduce the level of pollutants in the East Branch of the Finniss River, reduce public health hazards, reduce pollution levels in the open cuts, and implement aesthetic improvements [NTDME 1986].

The rehabilitation project had to address the particular climatic features of Rum Jungle, the six-month long dry season with its grass fires, the often heavy rain at the beginning of the wet season, and the high intensity rains associated with storms. In the 1970s, fish kills occurred in the Finniss River with the first flows of the wet season which tended to flush heavily polluted water which had been concentrated over the dry season. The rehabilitation project included treating the polluted water in the open cuts, covering the waste rock dumps, relocating the tails and heap leach material; and redirecting surface water flows on the site [Allen and Verhoeven 1986], as shown in Fig. 2.

4.1. Tailings and waste rock

Covers on the waste rock dumps were designed primarily to reduce percolation of rainwater through the dumps and they also reduced the oxidation rate within the dumps by reducing oxygen supply. After the dumps were reshaped to reduce erosion, they were covered with a three-layer system:

- first, a layer of compacted clay to prevent infiltration of rainwater,
- second, a layer of sandy loam to support vegetation and prevent the clay layer from drying out; and
- on top, a layer of gravelly sand to provide erosion protection and reduce moisture loss during the dry season.

Engineered run-off channels and erosion control banks were constructed on the tops and sides of the dumps and vegetation was established to stabilize the surface against long term erosion.

The tails and the residues from the copper heap leach pile were removed and placed in one of the open cuts, which was then covered with the same three layer system used for the waste rock dumps.

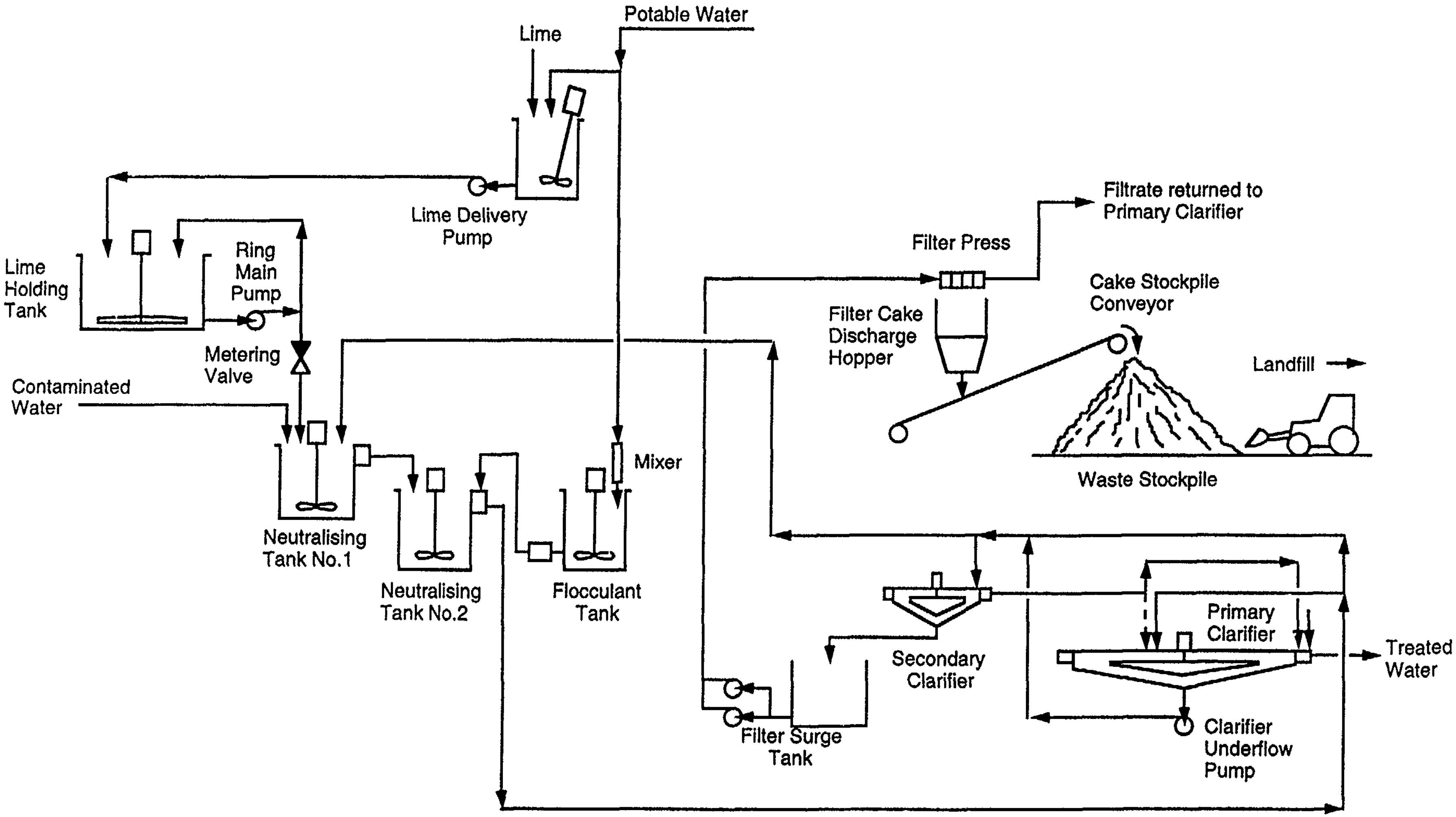


FIG. 3. Rum Jungle treatment plant — flowsheet.

4.2. Water treatment

Acid water in the other two open cuts was treated to neutralism the water and precipitate heavy metals. Treatment was necessary as the contaminated water was seeping through the pit walls and entering the river system. A water treatment plant with a capacity 430 m^3 h^{-1} was built to treat the water by lime neutralization. The difference in density between the water in the larger open cut and the treated water meant it was feasible to return the treated water to form a stratified layer above the polluted water in the open cut. Raw water was drawn from well below the surface of the pit and treated water returned via a low velocity discharge structure. This open cut was treated to a depth of 22 m. Following treatment, limestone was placed in the pit to assist with long term water quality stability.

The smaller open cut was treated by the direct addition of hydrated lime with the subsequent removal of the precipitated sludge from the bottom of the open cut and dewatering in the water treatment plant. The water was mixed by aeration before addition of lime slurry. The filtercake sludges were buried, in an area above the water table, which had a low permeability clay floor. The groundwater at this site was sampled as part of the monitoring programme. The treatment plant flowsheet is shown in Fig. 3.

After the open cuts had been treated, the East Branch of the Finniss River was redirected to its original path through both open cuts. A set of weirs was constructed to limit flow through the open cut. The annual flushing of the open cuts during the wet season was designed to prevent build up of acidity and heavy metals.

4.3. Mill area

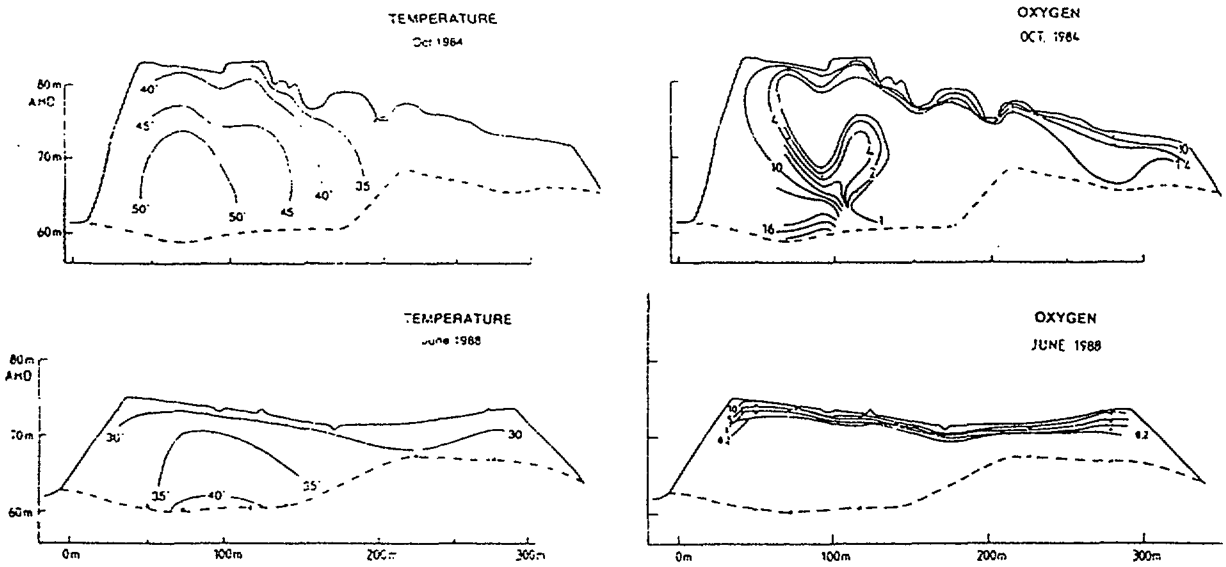
The uranium treatment plant and ore stockpile were 45 ha in size. The area was partly rehabilitated in 1977 by covering and revegetation. In the 1983–86 programme, acidic surface material was treated with lime and the other measures were undertaken, including contouring of the site to facilitate drainage, construction of erosion control banks and drains, and sealing of the area with an impermeable clay cover to prevent infiltration of rain water and leaching of contaminants.

4.4. Monitoring

A monitoring programme, was established as an integral part of the project to determine the effectiveness of rehabilitation measures. The programme commenced prior to rehabilitation works and continued until two years after completion. Site and water quality monitoring will continue until the project objectives are met and long term trends are established.

ANSTO has played a major role in monitoring at Rum Jungle. Pollution generation rates in the waste rock dumps before, during and for six years after rehabilitation were measured [Bennett et al. 1989, Bennett and Ritchie 1991]. Fig. 4 shows the differences in temperatures and oxygen concentrations in the dumps before and after rehabilitation. The clear decrease in the temperatures shows that the reaction rate has slowed down considerably following rehabilitation. Moreover, the fall in oxygen concentrations demonstrates that the cover system was successful in reducing the oxygen flux into the dump.

Ecological investigations conducted shortly after closure of the Rum Jungle site in the early 1970s characterized the mechanism, severity and geographical extent of the environmental impact from acid mine drainage, as measured by the diversity and abundance of freshwater fish and also macro invertebrates [Jeffree and Williams 1975]. These studies showed that fish and macro invertebrates were reduced in the Finniss River for a distance of 15 km downstream of the confluence with the East Branch and very few fish and macro invertebrates survived in the 12 km region of the East Branch, directly downstream of the Rum Jungle mine site. Follow-up ecological surveys since the rehabilitation have shown that fish diversity and abundance in the impacted region of the Finniss River have been returned to natural levels and fish populations have even returned to over half the length the East Branch.



Temperature Contours are marked in °C and Oxygen Contours in Percent Oxygen (by Volume)

FIG. 4. Temperature and oxygen distribution in intermediate dump before (October 1984) and after (June 1988) rehabilitation.

4.5. Institutional controls

The area has been declared a 'Restricted Use Area' under State legislation and all activities on site are closely supervised. The site is not suitable for permanent habitation.

4.6. Total cost of rehabilitation

The total cost of the 4 year rehabilitation programme completed in 1986 was $18.6 million. Ongoing monitoring and maintenance costs are still being incurred.

5. RESTORATION IN A DRY CLIMATE-MARY KATHLEEN URANIUM

Mary Kathleen is located near Mt Isa in north-west Queensland. The climate is dry with an average annual rainfall and evaporation of 450 mm and 2700 mm, respectively. Rainfall is highly variable, falling mostly in summer as localized storms or under monsoonal influence. Artesian bores provide the major source of water in the region but it is generally suitable only for stock watering purposes.

The uranium orebody was mined and processed in two phases from 1958 to 1963 and from 1976 to 1982. A total of 31 million tonnes of material was recovered from the open pit, including 7 × 106 t of ore at an average grade of 0.2% U_3O_8. The open cut is roughly circular in shape with an area of about 25 ha and a depth of 230 m. After radiometric sorting, the ore was processed by conventional acid leaching. Tailings were pumped as an acidic slurry to the tailings dam about 1.5 km from the mill. The tailings were deposited by the beaching method.

The tailings dam was constructed across a narrow section of a valley and had a retention area of about 30 ha. Two intermediate embankments were constructed, effectively dividing the dam into three sections at different levels. This enabled the final slope of the tailings surface to be kept to about 1 in 200 to minimize erosion. Water from the lower dam was decanted into evaporation ponds with a total area of 60 ha and a capacity of 2.5 × 106 m^3 [Ward 1985].

Seepage control was an important aspect of both the operational and rehabilitation phases. The principal seepage path under the evaporation pond wall was along the original stream bed. This was impounded in a collection pond and pumped back to the evaporation pond or to the treatment plant for reuse.

A detailed account of the decommissioning of the Mary Kathleen site is given in IAEA [1992]. The major points from this description are summarized below.

5.1. Decommissioning of mine and mill

Access roads to the pit were blocked off and the pit was filled to a depth of 50 m with water. Useful structures and equipment in the mill were decontaminated and sold. Remaining contaminated equipment was buried in the tailings dam. Uncontaminated discarded equipment was disposed of at the bottom of the mine.

5.2. Tailings and water management

The tailings dam and evaporation pond were covered with a 0.5 m layer of compacted soil/clay mixture, followed by a 1 m layer of waste rock material. These were then levelled, contoured and seeded. Radon flux data for the design of the cover system and leaching rates of tailings were provided by ANSTO [Ward et al. 1984, Hart et al. 1986].

To accelerate the decommissioning process, several steps were employed to reduce the volume of water in the evaporation ponds. Infiltration trenches were dug in alkaline clays where neutralization and cation exchange rapidly improved the water quality of any seepage. The seepage from the trenches was picked up by pumps in the borehole system and pumped back into the mine pit.

An additional seven hectares of evaporation area was also built around the perimeters of the original evaporation ponds to compensate for the lower than expected infiltration rate from the trenches. The remaining liquid in the temporary evaporation area was then treated with finely crushed limestone to precipitate dissolved salts and radionuclides. Following a drying period, soil and waste rock material were added to the resulting precipitate to assist solidification and provide a suitable base for the cover material. This material was placed in the tailings area and covered with soil and waste rock. The infiltration trenches were cleaned up and revegetated.

5.3. Waste rock piles

Waste rock piles and sorter rejects totalled about 24 × 106 t and occupied an area of around 64 ha. The surfaces of the piles were levelled and covered with a layer of rock containing suitable fine material to promote growth and attenuate radiation levels.

5.4. Monitoring

Detailed monitoring was undertaken throughout the rehabilitation works which took place over 3 years. Following a year of post rehabilitation monitoring, the programme was revised to a surveillance level. For example, monitoring of surface and groundwater near the tailings and evaporation ponds was undertaken for 2 years following cleanup. This involved monitoring levels of seepage from the tailings storage area into the groundwater and levels of surface seepage flow to establish long-term stability of the dam embankment, chemical analysis of sediment deposited along the initial section of the drainage line and water quality studies.

Radon concentrations in air were measured by Tracketch continuous sampling units at stations located around perimeter of area. Radon levels were found to be significantly below the accepted background levels. Gamma radiation measurements taken in the year following rehabilitation showed the levels to be below the accepted limit for members of the general public.

5.5. Cost of rehabilitation

The total cost of entire rehabilitation project was in excess of AUD$18 million. The project was successfully completed in 1984 without any subsequent requirements for institutional control. The project received an environmental award for excellence.

6. REHABILITATION PLANNING AND ENVIRONMENT PROTECTION AT THE RANGER MINE

The Ranger operation is one of the most highly regulated mine in the world. It is subject to 50 separate Acts of the Commonwealth and the Northern Territory. Ranger is monitored by two environmental authorities which independently supervise the mine's operation. For these reasons, environmental protection at Ranger Uranium Mines was given high priority right from the planning stage.

The Ranger mine site covers about 5 km^2 and is surrounded by 19 800 km^2 of Kakadu National Park. The site has been disturbed by the construction of the following:

(i) the processing plant;
(ii) ore stockpiles;
(iii) waste rock dumps;
(iv) the open-cut mine;
(v) water retention ponds; and
(vi) the tailings dam.

The climate is an overriding factor in the operating strategy and rehabilitation plans. The seasons are distinctly 'wet' and 'dry'. Rainfall in the wet season varies from 700 to 2200 mm, with torrential downpours often causing turbulent run-off through local creeks. By comparison, the dry season brings drought conditions. Rain is the major source of water, but potable supplies are obtained from bores and groundwater seeps into the pit.

6.1. Tailings management

Ranger are currently mining ore from the No. 1 orebody. This pit will be mined out this year, although a lot of broken ore still remains on the ore stockpiles. The No. 1 orebody contained some 53 000 t of U_3O_8 in 15.9 × 106 t of ore grading 0.33% U_3O_8, at a cut-off grade of 0.1% U_3O_8. A further 6.3 × 106 t of low grade ore was defined in the grade range 0.05-0.1% U_3O_8. The overall ore: waste ratio is around 1:3.8 and the final open cut will measure 750 m × 750 m × 175 m deep. The mill generates over one million tonnes per year of tailings which are neutralized with lime and pumped to a 100 ha, above-ground tailings dam.

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 significantly less than estimated for sizing of the tailings dam. When subsequent research showed that maintaining the tailing in a moist state was sufficient to achieve the desired radon release rate, tailings were deposited by the semi-wet technique and maintained in a saturated condition. Following this change, increased settled densities were obtained.

The rehabilitation timetable for the tailings dam is dependent on development programmes currently under consideration. One option is for the simultaneous development of the No. 3 orebody and the North Ranger deposit (an underground mine) about 20 km away [Barrowetal. 1994]. In this option, the preferred plan is to deposit tailings from these operations in the No. 1 pit and the current tailings dam would be retained for the life of the operation and used as a water reservoir and evaporation pond. In the long term, a decision on whether to leave the tailings in the current dam or transfer them to pit No. 3 will have to be made. If the tailings remain in the dam, the dam would be dried out, stabilized and capped with a cover of clay, rock and vegetation. The No. 1 pit would also be capped, with the No. 3 pit possibly filled with water to form a lake with appropriately graded shores and landscaping.

6.2. Water management

At the Ranger site, water management has assumed more importance than the other environmental aspects of uranium mining operations. The water management system at Ranger segregates water according to its degree of contamination which gives a greater range of treatment/disposal options, both during the operational phase and when decommissioning is undertaken. Essential principles are to minimis water collection in catchments and maximize recirculation of water. The system has three basic aims:

- to control run-off and seepage from the mine, mill, waste dump and ore stockpiles;
- to prevent siltation of the creek systems by retaining material eroded from the dump and stockpiles; and
- to make water available for ore processing.

All rainfall run-off from disturbed areas of the mine site is collected in one of four retention ponds (RP1 to RP4) and handled according to strict procedures which vary depending on the water quality. For example, water used in the milling operation must not be released, remaining in a closed circuit until it evaporates.

At the other extreme, run-off from undisturbed natural bush in the mining area has flowed into a nearby creek for the past 10 wet seasons without any environmental harm. The functions of the pond system are as follows [RUM]:

RP1: This pond contains run-off from 250 ha of natural bush and zones disturbed by construction activities. It meets drinking water standards and overflows to a creek.

RP2: Rain that falls on ore stockpiles, the mine pit and other areas around the process plant is collected in RP2. This water contains low levels of contaminants and is used as process water in various parts of the site and for dust control in the mine. When this pond is full, the water is dispersed by irrigating 35 ha of bush and by watering lawns and gardens around the site. Biological testing of the native scrubland has detected no adverse effect. Water from RP2 can be released into the local creek system, but only under certain flow conditions.

RP3: This is a small pond which is part of the closed circuit water system which includes the tailings dam and uranium mill.

RP4: The RP4 pond collects water that falls on the waste rock dump. Waste rock is below-ore-grade material. Water filtering from the dump contains low levels of uranium and concentrations of Mg, Ca, S and Na higher than in RP1. When RP4 is full, its quality complies with drinking water standards. RP4 water is used as a supply of "good quality" water to the mine, and small volumes are released periodically into a local creek.

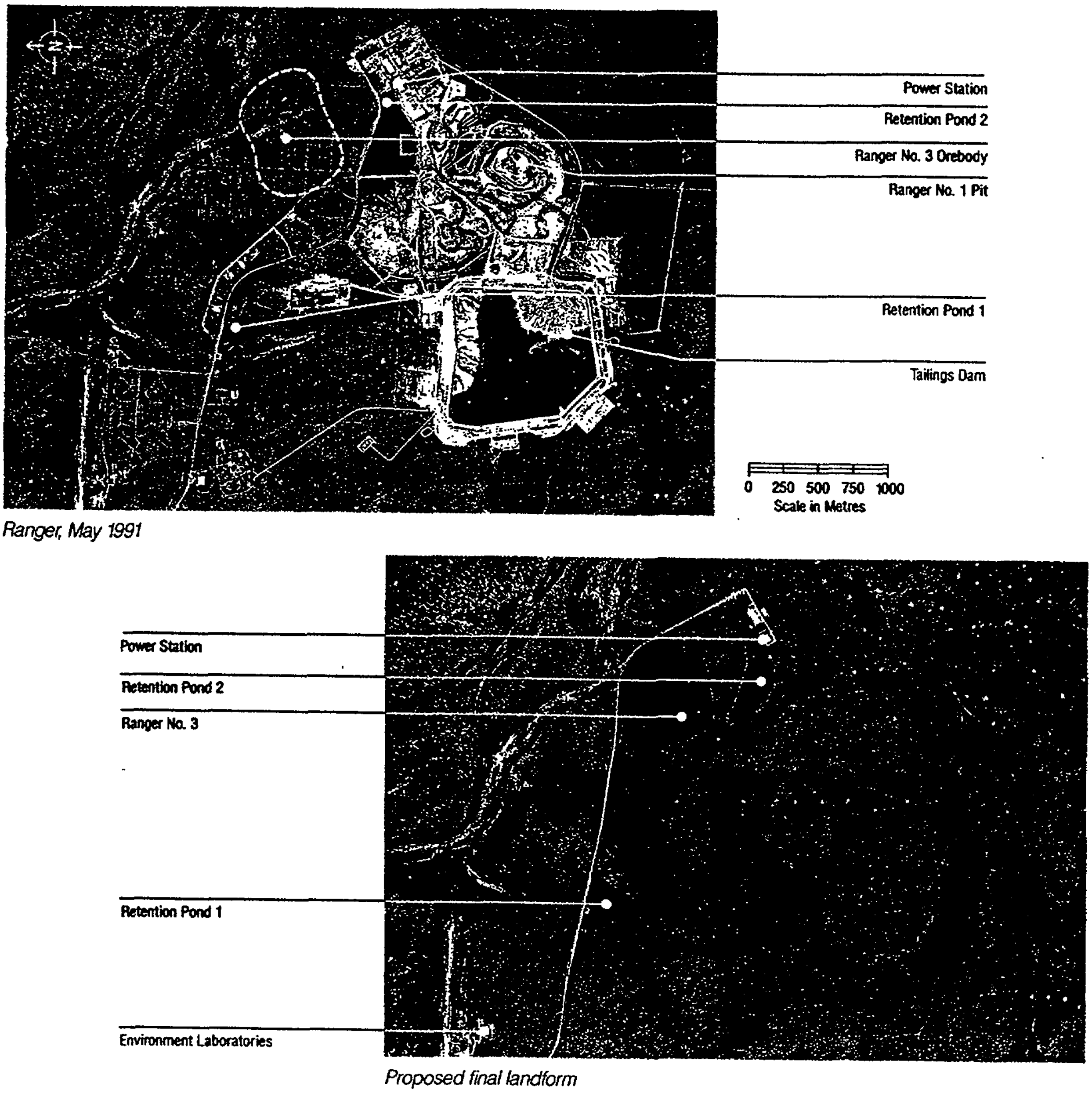


FIG. 5. Proposed final landform and current site plan (after RUM 1992).

6.3. Rehabilitation strategy

Rangers preferred rehabilitation strategy for the mine site involves construction of a 5 km^2 landform from waste rock and below ore grade material (see Fig. 5). The objective is to produce a rehabilitated landscape that will release contained elements at a rate and loading that is not significantly different from the natural landforms of the region, which is naturally highly mineralized [Unger 1993].

Once fully rehabilitated, the Ranger landscape will appear as a low rounded hill rising to a maximum height of about 24 m above the surrounding area at the site of the present tailings dam [RUM 1992]. The hill will have gently sloping sides and will be covered with trees and undergrowth to match the surrounding bush. Surface preparation will be designed to minimis infiltration into the tailings, but the remainder of the landform will require no special surface treatment. Slow flowing run-off will be collected in wetlands as a passive treatment before filtering into nearby waterways. The proposed plant retains the retention ponds for sediment control and makes extensive use of waste rock from Ranger No. 3 to cover the tailings dam.

The key requirements of the decommissioning programme are [Barrow et al. 1994]:

- management of tailings disposal and prevention of their dispersal;
- passive management of water releases from the abandoned mine sites and the acceptability of these waste waters in the environment;
- management of rock waste such that erosion loads do not cause a downstream depositional problem.

6.4. Rehabilitation planning and research

Rehabilitation of the project area is planned at three levels in accordance with the following goal and objectives which are incorporated into the Ranger Authorisation to Operate [Unger 1993]:

Goal: To establish an environment in the Ranger Project Area that reflects, to the maximum extent that can reasonably be achieved, the environment existing in the adjacent areas of Kakadu National Park, so that the rehabilitated area could be incorporated into Kakadu National Park without detracting from Park values of adjacent areas.

Objectives: To revegetate the disturbed sites of the Ranger Project Area with local native plant species in similar density and abundance to that existing in adjacent areas of Kakadu National Park, in order to form an ecosystem, the long term viability of which would not require a maintenance regime significantly different from that appropriate to the adjacent areas of the Park. To establish stable radiological conditions on disturbed sites of the Ranger Project Area so that, with a minimum of restrictions on use of the area, the public dose limit will not be exceeded and the health risk to members of the public, including traditional owners, will be as low as a reasonably achievable. To limit erosion in rehabilitated areas, as far as can reasonably be achieved, to that characteristic of similar landforms in surrounding undisturbed areas.

Since 1987, rehabilitation has been planned at three levels [Unger and Milnes 1992]:

- the long term conceptual plan for the mine site at completion of mining operation;
- the five year plan which is updated regularly as new developments take place and results from investigations are made available; and

- an annual plan which specifies necessary rehabilitation investigations.

The results of research projects provide input into the continued development and fine tuning of the rehabilitation plan.

6.4.1. Long Term Plan

The long term plan sets the shape and size of the final landform on the basis of mine plans which provide estimates of total quantities of waste products. Conceptually, the final landform will be kept as low and flat as possible to minimis the likelihood of serious erosion, while considering also the practical aspects of dump development and haul distance from the mine. The southern part of the proposed landform will be completed during mining of Pit No. 1, while the northern part will be constructed of waste materials form orebody No. 3. Construction of the landform is planned so that progressive shaping and vegetation can be undertaken.

Research to support this plan includes:

- investigations of weathering processes and products in waste rock;
- slope stability;
- revegetation and construction of sustainable ecosystems;
- hydrology of constructed landforms and solute transport; and
- contaminant mobility in wetlands.

6.4.2. Five Year Plan

The five year rehabilitation plan is based on mine and mill plans which identify the quantities of materials that must be placed for minimal ground disturbance and in line with the preferred landform design. Some key areas of mine development affect the five year plan. For example:

- the size of stockpiles significantly affect water management; and
- tailings deposition strategies influence the size of the tailings dam.

Research which impacts on the five year plan has included:

- water disposal by land application — spray and flood irrigation; and
- tailings deposition management including sub-aerial and acid tailings deposition, recycled water chemistry and use of magnesite as an alternative neutralizing agent.

6.4.3. Annual Plan

Each year the progressive rehabilitation (erosion control, revegetation) for the following year is devised and an amended plan of rehabilitation is submitted to the Federal Government for independent assessment of the funds to be kept in a Rehabilitation Trust Fund.

6.5. Cost of rehabilitation

Ranger has spent \$40 million directly on environmental management, with another \$70 million spent by others for research and support of supervisory organizations. In addition, another \$50 million has been accumulated in the trust fund.

7. THE NABARLEK HIGH GRADE DEPOSIT

The Nabarlek ore body was located in Arnhem Land, an Aboriginal Reserve, about 60 km NE of the Ranger mine. The climate at Nabarlek is similar to Ranger. Because of the high grade and sufficiently small size of the Nabarlek deposit, a rapid mining technique was used to recover all ore in 4 months of one dry season, for stockpiling and subsequent treatment. Open cut mining was completed in October 1979 and the milling operation was completed in June 1988, with a small heap leach operation continuing for another 12 months.

Mining produced 2.3 million t of waste rock and 600 000 t of ore containing 10 860 t U_3O_8 at an average grade of 1.9%. During the mining operation, ore and below ore grade material (bogum) were placed on temporary stockpiles while waste rock was used to construct the permanent stockpile pad and water retention ponds. Top soil and excess waste were stockpiled separately for reclamation on project completion. Local clays were used to provide an impervious liner over the stockpile pad. When all ore was placed on the stockpile, the top was sealed with compacted impervious clay and the sides sprayed with gunite to reduce wet season water ingress, erosion and dust losses [Lucas et al. 1984].

Like Ranger, water management was a major issue at Nabarlek. The plant, stockpile, open pit and 2 run-off and 2 evaporation ponds were within a restricted release zone (RRZ) and no water was allowed to discharge from this area, except by evaporation and seepage. The run-off ponds were provided to retain rainfall within the plant and stockpile areas. This water was used for plant make-up.

7.1. Tailings management

Uranium was extracted by acid leaching at pH 1.5. The acidic tailings slurry was neutralized with lime and discharged in the mined out pit by the sub-aqueous technique. Like Ranger, the operating authorisation required a 2 m cover of water. Under these conditions the expected consolidation of tailings within the pit was not being obtained. In 1985, QML sought and received permission to use the sub-aerial method of deposition [Bailey 1989]. Because of the constraints posed by the shape of the pit, the end result was a combination of the beach discharge and sub-aerial techniques. To improve the efficiency of tailings deposition, and reduce the volume of water entering the pit, a thickener was installed adjacent to the pit to increase the density of slurry discharge which had been diluted to facilitate pumping to the pit.

7.2. Water management

Decant water from the tailings in the pit were recycled to the mill via a storage pond. Excess pit water was treated with barium chloride to remove radium, passed through a clarifier to remove the radium/barium sulphate precipitate, and the treated water pumped to an evaporation pond. The precipitate was returned to the pit.

7.3. Decommissioning/rehabilitation

When the ore stockpile was exhausted in 1988, the plant was placed in a care-and maintenance status while further exploration was undertaken. If new reserves are not found by the end of 1994, the plant will be dismantled and decommissioning completed. Decommissioning/ rehabilitation of other areas of the site have been in progress since 1989. The major technical areas involved are [Weatherhead 1986]:

(i) Tailings. The tailings deposited in the open cut have to be covered and the area revegetated. To achieve this, the large amount of water included within the tailings must be removed to ensure that once the site has been rehabilitated, there will be no further settlement of the tailings.

(ii) Water Management. All water contained in the system must be disposed of before decommissioning is complete. The water in the system at the end of the ore processing operation was about 10^6 m^3.

(iii) Process Plant. This must be dismantled, decontaminated and either buried in the pit or sold.

(iv) Revegetation. The final task is the reshaping and revegetation of the entire site so that it blends back into the existing woodland.

7.3.1. Tailings

When ore processing was completed in 1988, the overall density of the 60 m depth of tailings in the pit was 0.9-0.95 t m^{-3}. The predicted settled density after final compaction was 1.1-1.2 t m^{-3}. The estimated time for natural drainage to achieve the desired removal of water from the interstices exceeded 10 years. The method chosen to accelerated compaction was the installation of vertical strip drains, known as wicks.

The installation of the wicks required access of heavy machinery (up to 60 t) onto the tailings surface. The change to semi-dry discharge of tailings in 1985 was partly successful in that, when the tailings surface was allowed to dry, access by light vehicle was obtained.

The procedure used for installation of the wicks was as follows. After allowing the surface of tailings to dry for 2-3 weeks, a layer of geotextiles was placed on the surface. This was covered by a layer of free draining stone. The best material for this coverage was bogum material which had the fines material removed for treatment by heap leaching. As this material was in short supply, it was supplemented by finer, but still free draining material, from the waste rock stockpile. The average depth of fill material on the tailings was 2 m, compared to the design thickness of 1.5 m [Bailey 1989]. The wicks were then driven to depths of up to 30 m at about 3 m centres. Water forced up through the wicks was irrigated in the pit catchment.

When the pit is to be rehabilitated, layers of rock fill will placed over the entire tailings impoundment which will then be protected by rock mulch, topsoil and vegetation. The total thickness of cover will be greater then 20 m. Water expelled during this final consolidation will remain within the rock voids and be retained by the impermeable pit walls.

Based on present rates of erosion, it is expected that it would take more than 200 000 years for the ground surface to erode down the tailings. This compares with the Guideline of the Code of practice which requires preparation of a tailings impoundment with a design life of 200 years and a structural life of 1000 years [Weatherhead 1986].

Infiltration of groundwater is a potential problem for sub-grade disposal of tailings. At Nabarlek, he pit is relatively impermeable, this was confirmed by monitoring during the operational phase, and major water movement from the tailings is not expected, except over a very long term.

7.3.2. Water Management

QML have investigated in detail methods to accelerate water disposal. Release to a local creek was the preferred option, but this was rejected as being unacceptable to the Traditional Land Owners.

Surface irrigation was considered the second most attractive option. After 2 years of experimentation, permission was granted in 1986 to pump 400 000 m^3 of evaporation pond water into irrigation areas. The field tests showed that ground chemical, bacteriological and mechanical filters would attenuate sulphates within the soil and prevent the passage of high concentrations of solute within the groundwater.

The irrigation areas consisted of 10 ha of forest land adjacent to the site and a similar area of distributed land on a clay subsoil. The irrigation system was designed for extreme rainfall events so that most water was disposed of over the last 2–3 years of the life of the mine.

7.3.3. Process Plant Removal

When the plant is dismantled, it will be thoroughly cleaned and motors and instruments removed. All pipework and overhead gantries and similar structures will be deposited in the pit. Each major item will be inspected to estimate the amount of decontamination work required and assess whether sale or disposal is the most economic alternative.

Once the mechanical plant has been removed from the site, the foundations will be removed. Grinding mill and other foundations may need to be demolished using explosives. Other foundations for tanks and concrete slabs will probably be ripped up and all surplus concrete removed to the pit. Anything deeper than a metre will be left in place and covered with a layer of either waste rock or laterite, levelled to an approximation of the original surface contours, covered with top soil and revegetated.

7.3.4. Revegetation

The pit surface will be recontoured back to an approximation of the original contours. The area of the plant site will be revegetated with an imported grass and local trees. The area occupied by the stockpile mound and evaporation ponds has been levelled and will be returned to an approximation of the original contour using local vegetation. The evaporation pond has been scrapped to remove salt residues (mainly ammonium sulphate) which have been deposited in the pit.

When rehabilitation is complete, QML will provide a monitoring and inspection service to repair damage that may have occurred in the wet season and to check the progress of revegetation.

7.4. Cost of rehabilitation

The NT Government has required a rehabilitation guarantee of AUD$10 million. This figure has been confirmed as reasonable by the appropriate Federal Department.

8. THE OLYMPIC DAM COPPER–URANIUM DEPOSIT

Olympic Dam Operations (ODO) is a copper–uranium–gold–silver deposit which commenced operation in 1988. Current ore production from the underground mine is 2.4 million tonnes per year, averaging around 0.08% U_3O_8, but this will soon be increased to 3 million tonnes per year, when expansions have been completed. The total inferred resource is estimated to be 2100 million tonnes of ore, ensuring that the project will have a very long life. For this reason, a long term expansion group has been formed to assess all aspects of future operation.

Olympic Dam is unique from a metallurgical viewpoint in that four high quality products, uranium, copper, gold and silver, are produced on the one site [Olympic Dam Operations 1994]. The metallurgical flowsheet for uranium recovery is similar to that for Ranger, but the climate at Olympic Dam poses different issues in terms of environmental protection and eventual decommissioning. The Olympic Dam environment is arid, summers are very hot, winters are mild, there is low rainfall averaging about 160 mm annually and droughts are frequent. There are no natural water courses in the area.

The water used at ODO is extracted from a wellfield in the Great Artesian Basin, the edge of which is located 100 km north of the mine. Current water usage is around 13 ML/day.

8.1. Tailings management

About twenty per cent (by weight) of the tailings from leaching are used to prepare backfill for the underground mine. The underflow tailings slurry from the CCD washing circuit is deslimed through clusters of cyclones to separate the coarse sand from the tailings. The washed sands are then neutralized with a lime slurry and pumped to the backfill preparation plant. Backfill in the form of cemented aggregate fill is produced in a batch process by mixing coarse tailings, crushed waste rock, Portland cement and flyash.

The slimes fraction from the cyclone separation plant is pumped as a 30 wt% slurry (pH 1.5) to the tailings storage area, where the tailings are deposited by sub-aerial deposition. For start-up, a storage area of 75 ha by 10 m high was constructed. Unlike some sub-aerial systems, water is not withdrawn from a central sump, but is allowed to pond in the middle and evaporate in-situ. In 1991, the tailings storage area was expanded by construction of an adjoining 100 ha embankment system. This area is divided into two cells.

8.2. Water management

Adjacent to the tailings storage area is sited a 50 ha evaporation pond for acidic mill liquors (e.g. raffinate bleed). A separate 15 ha clay pan is used for evaporation of saline water pumped from the aquifer overlying the orebody. Because of the highly saline nature (TDS = 25 g L^{-1}) of the groundwater in the Olympic Dam area, which make it unsuitable for stock or human consumption, run-off from waste rock and ore stockpiles is not of the same concern as at Ranger.

In the unlikely event that seepage from the tailings storage area reached the groundwater table (at 50 m depth), it would enter the cone of depression associated with dewatering of the mine. Seepage would then be drawn into the dewatering wells and pumped to the saline water evaporation pond.

8.3. Effect of operating methods on rehabilitation requirements

The cost of tailings rehabilitation, and potential environmental impact, would be reduced if the fines tailings materials could be used as backfill. Olympic Dam are currently investigating the possibility of producing a building aggregate from the fines tailings material for blending with coarse sand tailings for backfill. This approach has the potential to reduce the above ground storage of tailings by 50% (and the associated cost of storage construction). One technique under consideration involves blending the tailings with a material having a suitable energy content and sintering the blend into an aggregate with the desired structural integrity [ODO Private Communication 1994].

Water is a valuable resource at Olympic Dam. The cost of obtaining additional water for planned expansions will be high as the capacity of supply pipeline will have to be increased. Options for recycling acidic tailings water to various parts of the process are being examined ~ODO Private Communication 1994].

8.4. Decommissioning/rehabilitation plan

As the project is relatively young, in terms of its expected life, there has not yet been significant opportunity or need for progressive rehabilitation or revision of decommissioning plans. Drill sites, unused roads and borrow pits are rehabilitated as soon as they are no longer required. Monitoring of these sites is providing a gauge of the effectiveness of mine site rehabilitation procedures.

Decommissioning of the tailings storage facility will be accomplished by covering the surface of the tailings with a combination of clay material and quarried rock. The sub-aerial method of tailings disposal will ensure that the tailings attain a maximum practical density within the shortest possible time. Within a month of the deposition of the last layer of tailings, earthmoving equipment will commence placing the cover material [Kinhill-Stearns Roger 1982].

The tailings cover must provide an engineered barrier between the upper surface of the tailings and natural wind and water erosion forces. Present plans allow for an average of 1.5 m of clay material over the tailings surface, with a further 0.5 m cover of quarried rock over the clay material. (As there is a shortage of clay in the area, possible use of a thicker clay/sand mixture is being investigated).

When no longer required, the acidic liquor and the saline liquor evaporation ponds will be decommissioned and rehabilitated. The acid pond will contain a layer of deposited salts which will be excavated and placed into the tailings storage prior to the placement of the decommissioning cover.

The saline evaporation pond will also contain

a salt deposit which will be placed into the tailings storage together with any contaminated clay lining material and embankment fill.

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TECHNICAL REHABILITATION OPTIONS FOR FORMER MINING AND MILLING FACILITIES OF WISMUT GMBH

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Abstract

The predecessor company of Wismut GmbH had mined uranium deposits of five different types which varied in their geological settings and sizes. Milling sites also had different geological environments. In contrast to U.S. practice to apply general rehabilitation standards not on a site-specific basis, the German government has opted for rehabilitation targets following site-specific assessment and optimization procedures which take into account the relevant geological and hydrological situation, the mining history and the technologies used. *Vein type deposit of Schlema/Alberoda*: Cleansing, exploration and backfilling of near-surface historic mine workings. Filling of subsidence area. Mine flooding up to level of historic drainage adit. Treatment of discharge waters for U, Ra, and As over specified time frame, in situ rehabilitation of bulk of waste piles. Perpetual depression ventilation of near surface openings to protect the Schlema community against Rn concentrations. *Black shale type deposit of Ronneburg*: Controlled flooding of mine up to original ground water level using barriers to separate mine workings having differing contamination concentrations. Treatment of discharge waters. Waste-specific placement of most piles into worked-out open pit. *Sandstone type deposit of Königstein*: Removal of easily leachable uranium from leaching blocks while neutralizing circulating solution. Flooding of mine subsequent to flushing of deposit using a system of control tunnels in the outskirts of the deposit until compliance. Maximum protection of upper aquifers by sealing all penetrations due to mining. In situ rehabilitation of waste pile. *Coal type deposit of Dresden-Gittersee*: Flooding of mine up to level of drainage adit from historic coal mining. In situ rehabilitation of waste pile. *Deposits occurring in Upper Permian sandstones and limestones*: They were exploited by open-cast mining; worked-out open pits were used as tailings ponds. *Milling facilities*: Hydrogeological investigations of the surroundings of tailings ponds. Seepage collection; treatment and discharge of free water from tailings ponds. Dewatering and encapsulation of tailings in situ. Demolition of contaminated structures and excavation of contaminated soils at all sites.

1. INTRODUCTION

Uranium mining in the Saxonian portion of the Erzgebirge already began in the last century. From different mines some 17 tonnes of U were extracted. In addition to this, silver and non-ferrous metal mining since the Middle Ages had produced and dumped an unknown amount of pitchblende which was worthless at that time.

However, large scale uranium mining in the area began only after World War II by Wismut, then a Soviet stock company which was turned into SDAG Wismut, a joint Soviet-German stock company in 1954. That company undertook a systematic prospection for uranium in an area of 55 000 km^2, discovering five large scale, six medium scale and sixteen small scale deposits. By 1990, these deposits had produced a total of 251 300 t U, including all mining and milling losses.

Mining and milling of uranium ore by SDAG Wismut caused considerable impacts on both environment and population. Therefore, waste piles, tailings impoundment areas, haulage roads as well as near surface underground mine workings today constitute areas suspected of radioactive contamination. These suspect areas cover a surface of some 240 km^2. Current decommissioning, preventive action, and subsequent rehabilitation involve in a first stage some 37 km^2 of plant areas still used by Wismut. These include among others 1 520 hectares of waste piles, 724 hectares of tailings impoundments, a sizeable worked-out open pit as well as the underground workings of nine former mining sites (see Table I and Fig. 1).

TABLE I. WISMUT SITES AT THE BEGINNING OF RECLAMATION ACTIVITIES

	Aue	Königstein	Ronneburg	Seelingstädt	Total
Surface (ha)	569,4	143,4	1 670,3	1 314,8	3 698,3
Shafts	8	10	38	0	56
Waste piles					
- number	20	3	16	9	48
- footing (ha)	342,3	37,9	552,0	533,1	1 517,7
- volume Mm^3	47,2	4,5	178,8	72,0	311,5
Tailings ponds					
- number	1	3	3	7	14
- surface (ha)	3,5	4,6	9,0	706,7	723,8
- volume Mm^3	0,3	0,2	0,25	159,7	160,45
Mine workings					
- surface km^2	30,7	7,1	73,4	0	111,2
- acc. length km	240	112	1 043	0	1 395
Open pits					
- number	0	0	1	0	1
- surface (ha)	0	0	160	0	160
- volume Mm^3	0	0	84 (open)	0	84

According to their morphologies, structures, host rocks and genesis, these uranium deposits can be subdivided into five geological types. These five types account for the considerable differences that exist in mining and milling technologies, in contaminant contents of waste piles, in impacts on ground and surface waters, and because of that in specific rehabilitation objectives.

For these reasons, the German government has opted for rehabilitation objectives and standards to be defined on the basis of detailed site-specific assessment and optimization procedures.

Nevertheless, a certain number of common criteria are applicable to any site; to comply with a value of 1 mSv/a for the averaged effective dose equivalent over a period of 50 years of additional radiological exposures due to uranium mining, with recommendations issued by the Commission on Radiological Protection, with the ordinance on Nuclear Safety and Radiological Protection, as well as with pertinent legal requirements.

TABLE II. GEOLOGICAL CHARACTERISTICS OF TYPES OF DEPOSITS MINED BY WISMUT CORPORATION

	Type of deposit				
	Ronneburg	Veins	Sandstones	Carbonates	Bituminous coals
Uranium content (t)	$n \cdot 10^2$-$n \cdot 10^5$	$n \cdot 10$-$n \cdot 10^4$	$n \cdot 10^4$	$n \cdot 10^2$-$n \cdot 10^3$	$n \cdot 10^2$-$n \cdot 10^3$
Host/wall rocks	shales, limestone, diabase	shales, amphibolite	sandstone siltstone	dolomite, shaly clay	bituminous coal, carbonaceous shale
Age of host/wall rocks	Ordovician-Devonian	Precambrian-Devonian	Upper Cretaceous	Upper Permian	Lower Permian
Uranium minerals	pitchblende sooty pitchblende (Coffinite)	pitchblende (uraniferous mica)	pitchblende sooty pitchblende	sooty pitchblende	sooty pitchblende
Average uranium content in run-of-mine ore (% U)	0,08 - 0,09	0,4 - $n \cdot 1$	0,11	0,07	0,09 - 0,10
Associated minerals	-	Co, Ni, Bi, Ag	-	-	coal
Genesis	polygenic (supergene, hydrothermal?)	hydrothermal	epigenetic (infiltrated)	epigenetic (infiltrated)	syngenetic
Example	Ronneburg	Schlema, Tellerhäuser, Zobes, Johanngeorgenstadt, Annaberg	Königstein	Culmitzsch	Freital (Bannewitz, Gittersee)

Wismut AG 1991

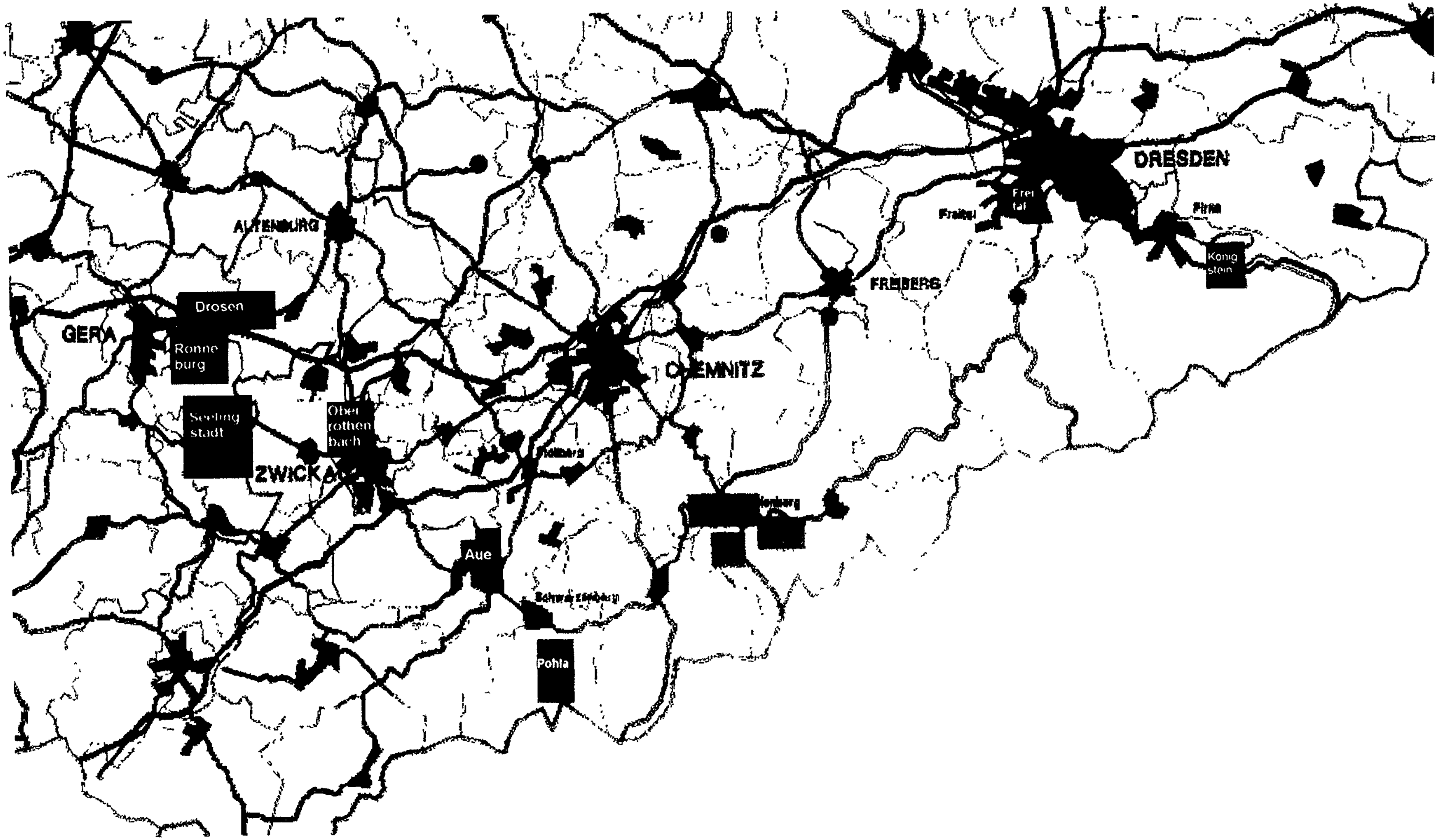

FIG. 1. Location map of suspect areas.

Next, I shall briefly describe some specific aspects of individual deposits and sites, and explain the relevant rehabilitation concepts.

Uranium mining started first in the vein deposits of the Erzgebirge and the Vogtland. Of the nine vein deposits, each producing more than 100 t U, and numerous small scale deposits in the Vogtland and Erzgebirge, only the deposits of Schlema–Alberoda and Pohla–Tellerhauser, that were mined by 1990, remain to be rehabilitated by Wismut GmbH.

2. AUE DISTRICT

The deposit of Schneeberg–Schlema–Alberoda is situated north of the town of Aue. It covers an area of approximately 10 km^2; its uranium-bearing zone of veins ranges from 1 to 3 kilometers and stretches longitudinally over more than 8 kilometers. Since the mid-15th century, the area of Schneeberg was intensely mined for silver and non-ferrous metals. Geologically, the deposit is situated in exocontact of the Aue–Gleesberg granitic massif, at the intersection of a syncline striking SW–NE and displaying schists from Ordovician to Devonian, carbonaceous schists, skarns, and metadiabases. The entire rock sequence is underlain by Late Variscan granites, cut off at a depth of approximately 2 200 m. Rocks are covered by thin layers of loose sediments. Uranium mineralization occurs in carbonate and quartz-calcite veins running northwest; besides pitchblende are also present sulphides, nickel-cobalt arsenides, native silver, bismuth and arsenic. Approximately 2 200 uranium-bearing veins have been identified in the area of the deposit. The deposit was developed down to a depth of 1 800 meters. In the period from 1949 to 1990 a total of some 79 800 t U were extracted. The run-of-mine ore contained an average of 0.4 to 0.6% uranium. Average uranium recovery ranged between 1.0 and 3.5 kg per square meter of vein (Fig. 2).

Loose rock and weathered zone together form a common ground water horizon; alimentation is by rainfall infiltration.

Precipitation and surface waters pass through these aquifers into underlying joint, fault, and vein zones in solid rock. These joint and fissure waters infiltrate into mine openings at a rate of 600 to 700 cubic meters per hour. In near surface areas, these waters are only slightly mineralized. At greater depths, their volume decreases, mineralization increases. Waters contain uranium, radium, arsenic, and other metals.

Purposeful flooding of the mine started early in 1991. It uses only part of the water influx, the remainder continues to be pumped out in order to retard the process of flooding so as to gain sufficient time for the rehabilitation of near surface mine workings, for ventilation modification, and for preparations for water treatment. By 1 April 1994, 7.3 million cubic meters of void space were flooded out of available mine voids of 39 million cubic meters.

Flooding is continuously monitored, sampled and measured. Water chemistry shows the following trends:

- reduction in oxygen concentration;
- increase in electrical conductivity;
- increase in arsenic and uranium concentrations.

This development requires the treatment of waters after completion of flooding prior to their discharge to receiving waters. A number of pilot-scale tests were conducted to chose the treatment procedure. The flooding of the mine is designed to stop at the level of the Markus–Semmler–Stolln adit which dates from the Middle Ages and when it served as a drainage adit for silver and non-ferrous metal mining. It will be possible to suspend the flooding at the minus 540 m level.

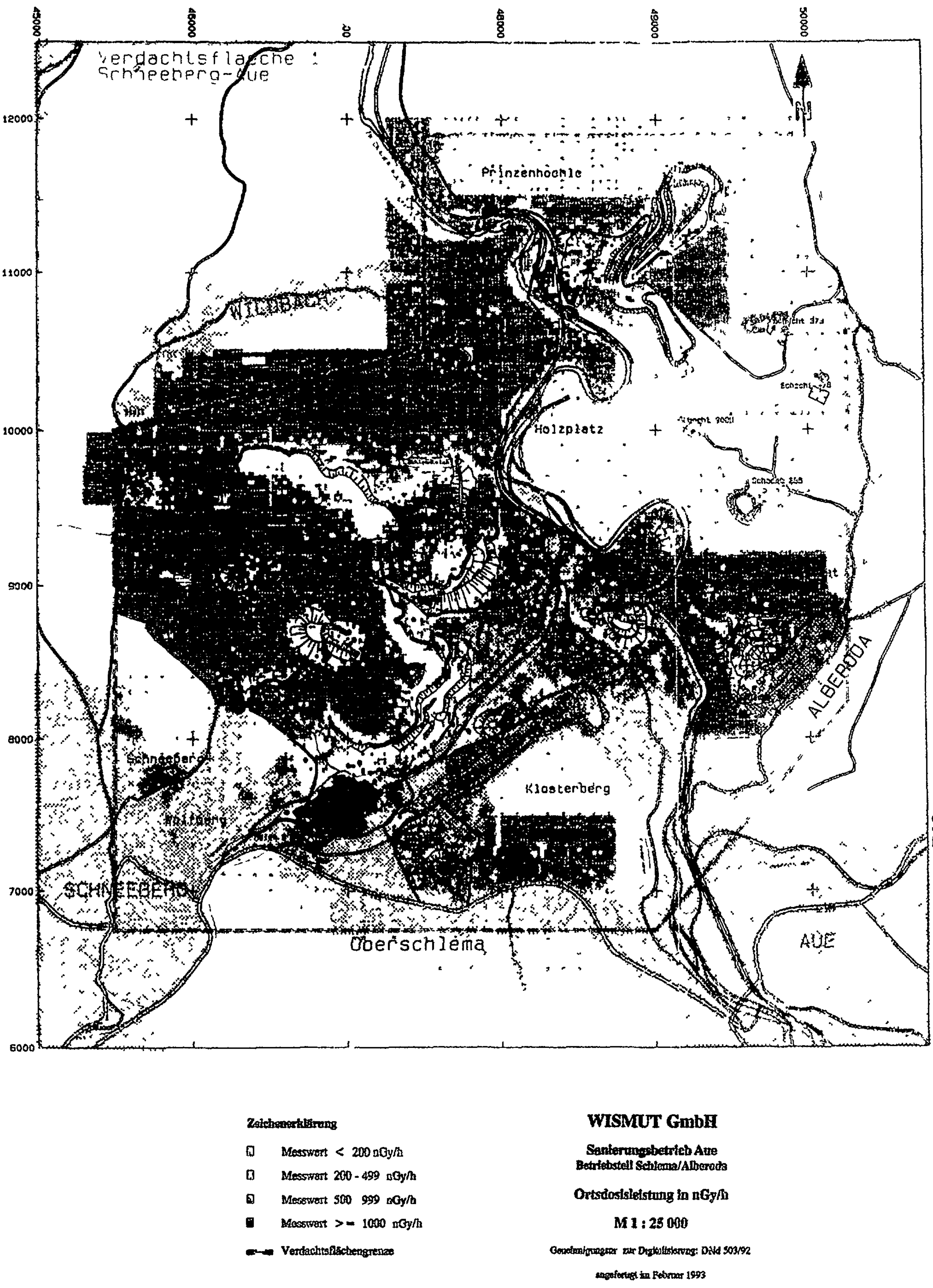

FIG. 2. Location map. Dose rates in the Aue area.

Open mine workings dating from the early years of uranium mining and situated above the level of the Markus-Semmler-Stolln adit will be prospected by geophysical means and subsequently backfilled. The subsidence zone overlying these mine workings was filled with heap material, covered with inert materials and vegetated.

Flooding and ventilation of the mine area are closely linked to each other. Up to now, return air from mine ventilation passed by one shaft isolated from surrounding communities. Once the flooding has reached the minus 540 meter level, this ventilation will be interrupted. This situation would result in an uncontrolled discharge of radon-loaded return air from non-flooded near surface mine workings which would concentrate in valleys of the Schlema community. Radon fluxes would amount to 5 000 or even 8 000 kBq/s. For these reasons, a new ventilation system will have to be in place prior to the flooding of the - 540 m level to ensure permanent evacuation of mine air at the level of the Markus-Semmler-Stolln adit by other shafts outside the Schlema community.

The mining site comprises 20 waste rock piles covering a surface of 342 hectares and having a volume of 47 million cubic meters. Due to their uranium and radium contents they constitute sources of radon and hence must be covered in order to keep additional radiological exposure at the Schlema community below the level of 1 mSv/a. At the same time, the cover is to prevent infiltration of precipitation and hence contaminant release from waste piles into ground and surface waters.

Assessments based on current experience predict that a cover of 1 m thickness would produce such an effect. However, any type of cover will require the flattening of slope angles from a ratio of 1:1.3 to 1:3. Zero availability of space will require in situ reclamation of most of the waste rock piles.

3. RONNEBURG DISTRICT

The most important deposits were found in Lower Palaeozoic schists, limestones and diabases (Ronneburg-type deposit). These deposits and occurrences have been found at different locations in the Eastern parts of the Thuringian Slate Mountains. The deposit near Ronneburg was the most important of these. Uranium mineralization was detected in an area covering 164 square kilometers; of these, approximately 74 square kilometers were developed. In the period from 1952 to 1990 the deposit produced a total of 113 million tonnes of ore of an average grade of 0.1 percent. The open pit contributed 13 percent to that amount (Fig. 3).

Uranium mineralization is present in a succession of beds which are approximately 250 m thick and composed of Ordovician clay schists, of Silurian carbonaceous clay and siliceous schists, of dolomitic limestones, and of Devonian calcerous slates and limes. Uranium was the only mineral of economic interest. The ore and host rocks typically contain up to 6 percent pyrite and up to 10 percent organic carbon. Resulting oxidation processes caused endogenous fires. Microbian leach processes going on in waste piles caused sulphate concentrations of up to 10 g/l and 1 000 degrees hardness in mine and seepage waters from waste piles.

Rock formations from Ordovician to Devonian form a number of complex saddles and synclines, striking for several kilometers at a width ranging from 200 to 800 meters. In the South, uraniferous strata series are cropping out at the surface while in the North they are plunging beneath Upper Permian and Triassic formations (Fig. 4).

Silurian schists and limestones typically form joint aquifers. Hanging and underlying Ordovician and Devonian schists typically form aquicludes. Upper Permian and Triassic beds contain three ground water horizons; the uppermost is used as a source of drinking,water.

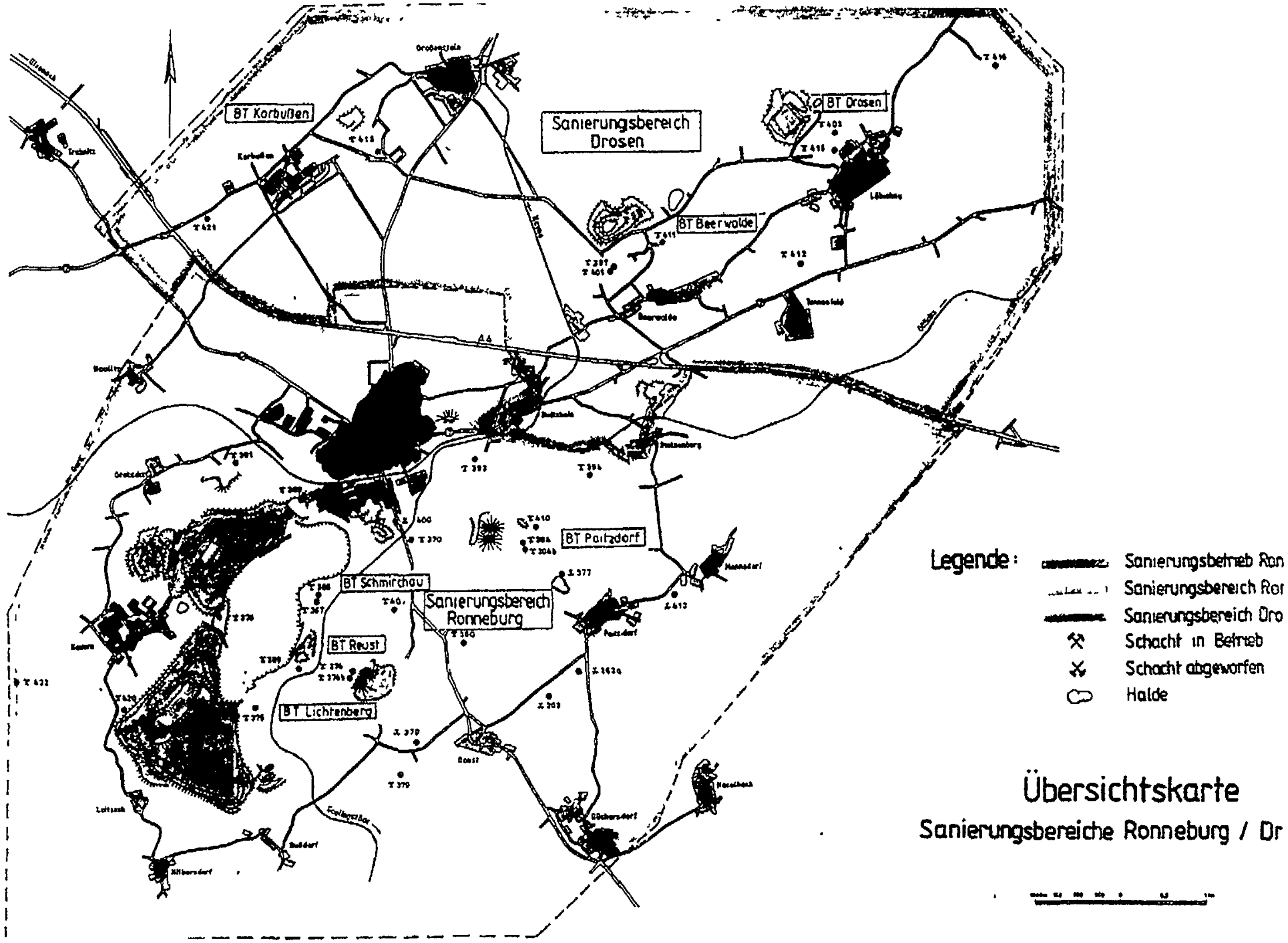

FIG. 3. Location map of Ronneburg.

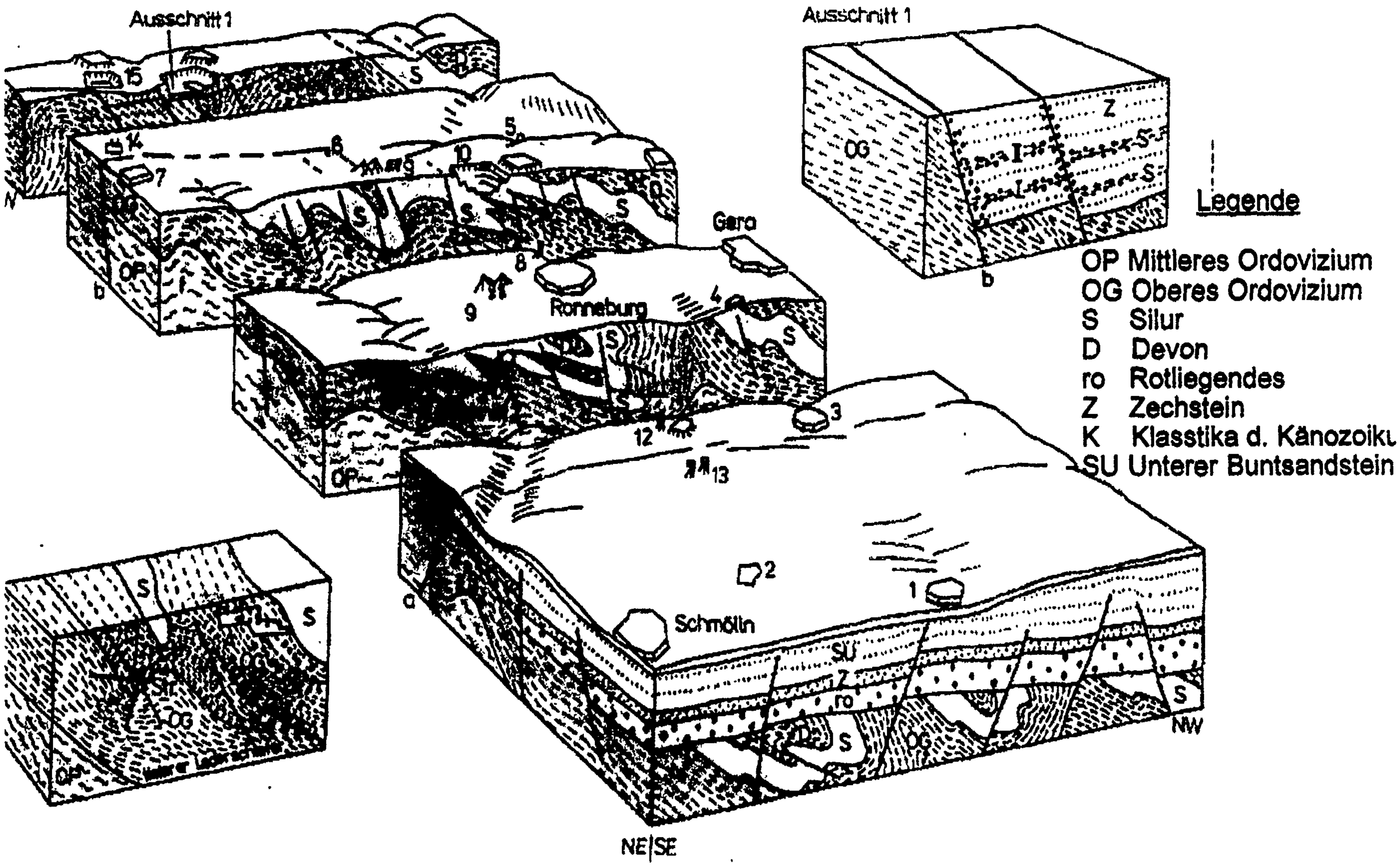

FIG. 4. Geological block diagram of the Ronneburg uranium deposit.

Major rehabilitation tasks comprise the maximum restoration of pre-mining hydrogeological conditions and the safe remediation of waste rock piles and the worked-out open pit.

Forty years of mine drainage have resulted in a depression cone of approximately 50 km^2. The lowering of the ground water table affected the upper weathering layers down to the lower part of the Silurian joint aquifer. Two basic options were under consideration for the restoration of the water table:

i) halt the flooding at a level between 60 and 240 meters below ground surface.

This option (i) presents the following advantages:

- no water will discharge at the surface;
- water can be collected at a central point for treatment

This option (i) presents the following disadvantages:

- high energy costs for drainage and ventilation;
- continued radon flux from underground workings;
- perpetual treatment of mine drainage;
- increase of aeration zone and permanent contaminant leaching;
- perpetual disturbance of pre-mining hydrological conditions.

(ii) flooding up to a maximum possible level of approximately 30 to 40 m below ground surface
This option (ii) presents the following advantages:

- lesser thickness of aeration and leaching zones;
- lesser volumes of water to be treated;
- situation close to pre-mining hydrological conditions.

This option (ii) presents the following disadvantage:

- decentralized outlet of contaminated waters.

After considering all the pros and cons, the second option (ii) was given preference.

Barriers will be provided to prevent major contaminant migration between mine sections of differently contaminated waters. Migrant waters are to be collected and pumped to a treatment plant.

Mining operations left behind waste rock piles covering a surface of 604 hectares and containing a total volume of 118 million m^3 of mine wastes as well as a worked-out open pit of 160 hectares having a residual volume of 84 million m^3. At the time of mining 79 million m^3 of waste rock already were dumped in the open pit mine .

Considerable amounts of contaminants were released from the waste piles due to oxidation of high pyrite contents in the rock and to natural microbian leaching. Hence, seepage in some places presents more than 1 000 degrees hardness, and contains 10 g/l sulphate, 3 mg/l U, and 200 mBq/l Ra. In order the reduce these releases, waste pile covering, in situ reclamation and relocation into the open pit were assessed.

Following a comparison of these options, the relocation of the major part of the waste rock piles into the open pit was chosen as the principle line of action (Fig. 5). The sequencing of the waste rock placement will be determined by the acid generating and neutralizing potentials of the individual waste piles. These potentials will be determined from the pyrite and carbonate contents, respectively, of the heap material. Waste rock showing high acid generating potential will, after alkaline addition,

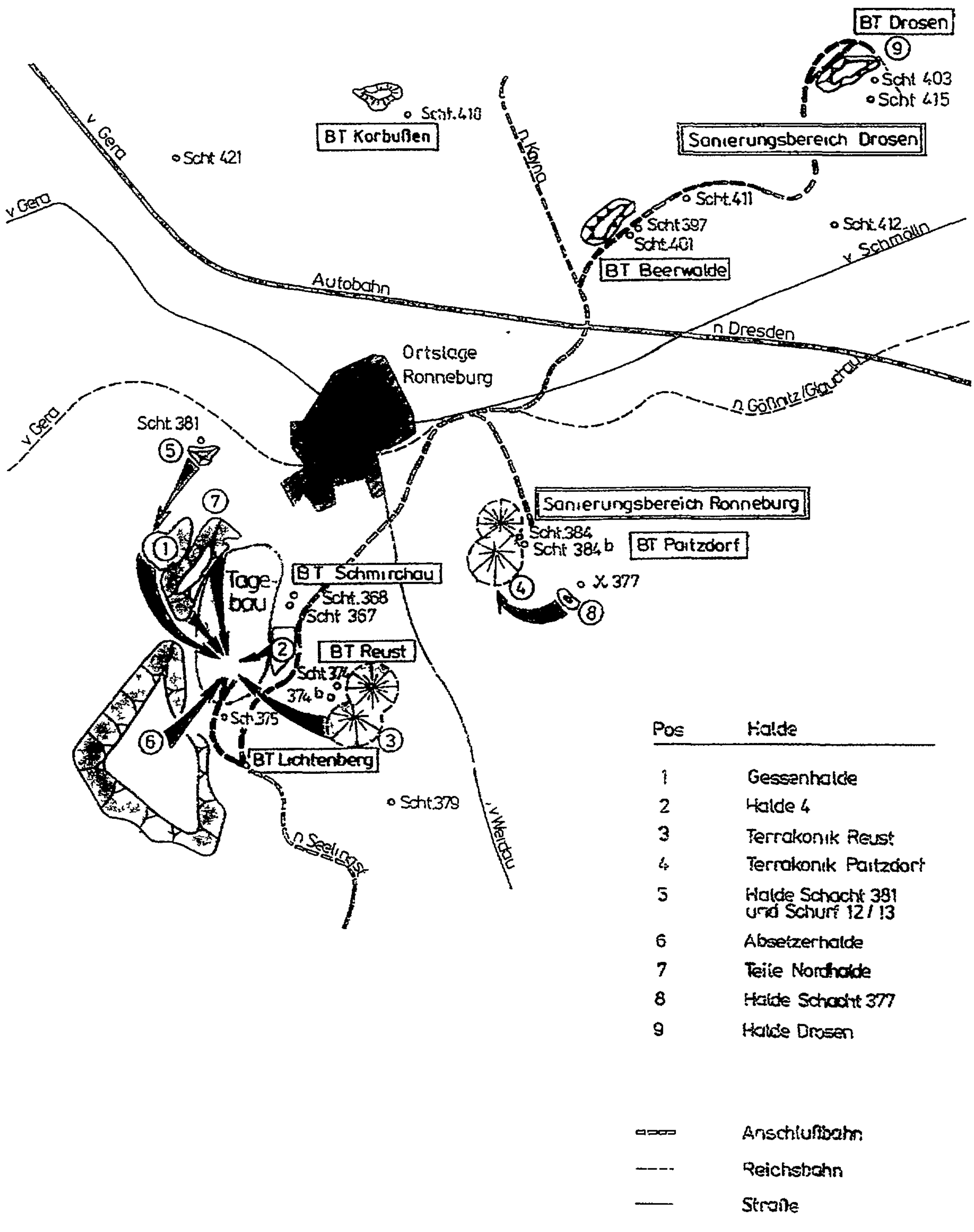

FIG. 5. Tailings relocation map of the Lichtenberg area.

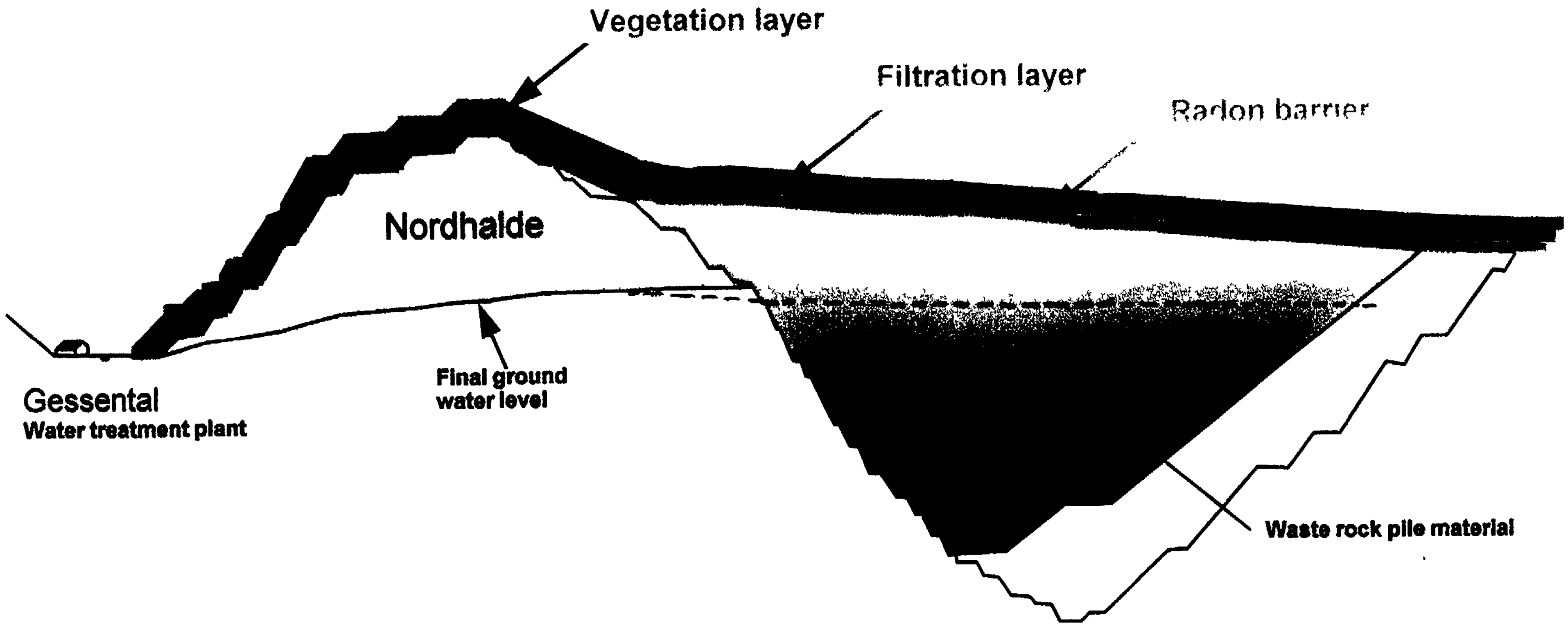

FIG. 6. Schematic description of open pit remediation.

be placed at the bottom of the open pit, that is to say below the level of the final water table after completion of mine flooding. In an effort to reduce radon exhalation and rainfall infiltration, a cover will be placed over the backfilled open pit (Fig. 6).

4. KÖNIGSTEIN DEPOSIT

Specific problems are to be resolved at the Königstein deposit. On the basis of analogue structures existing in the cretaceous fault troughs both in Saxony and Bohemia and on hints pointing to the occurrence of uranium mineralizations on the Czech side prospecting started in the Elbe valley of Saxony in 1961. By 1966, 1 200 boreholes had been drilled at the Königstein deposit. Development of the deposit was well under way before the end of 1966.

The Königstein deposit is situated in the Elbe trough valley striking NW–SE. Cretaceous sediments, several hundred meters thick, are overlying a basement formed of granites and granodiorites. Marine sandstones, approximately 300 m thick in the area of the deposit, imbedded with layers of siltstone and mudstone are flatly dipping NE at 1 to 3 to degrees. Basalts in diaclases are part of Tertiary vulcanicity and form pans (Fig. 7).

Uranium mineralization occurs in a zone striking NNE–SSW and consisting of terrestrial, lagoonal, and marine formations underlain by the succession. Total thickness of the ore-bearing series is up to 50 m.

Cretaceous beds contain four aquifers separated by sandy limes and clays. The three upper horizons are used as sources of drinking water at some distance from the deposit.

Until early in the 80s mining operations in the lowest aquifer used conventional room and pillar. In the period from 1967 to 1983, this method produced 12.7 million tonnes of ore of an average mineral content of 0.095% and 12 000 t U. In situ extraction of low grade ore by sulfuric acid leaching was first attempted in 1968 and supplanted conventional mining in 1984. Depending on the permeability of the rocks, blasting was used to fissure them before sulfuric acid was injected from drifts. Where rock permeability permitted, acid injection was conducted from boreholes. The pregnant liquor was collected at the bottom and pumped to the surface. After sorption of uranium, the barren liquor was again added to the leach circuit.

When operations where shut down in 1990, 750 000 m^3 of leach liquor were in the circuit. This liquor is to be neutralized and discharged into receiving waters after radium precipitation by barium chloride. The removal of approximately 1 million m^3 of leach liquor trapped in rock pores is much more difficult to achieve. When the mine workings will be flooded, the flooding waters will replace and dilute this liquor. For that reason, a drainage system will be established in the northern part of the mine area where flooding waters will be collected, treated, and returned to the flooding voids until regulatory compliance is reached (Fig. 8).

This procedure is required in the first place to compensate for insufficient sealing between the mined lower aquifer 4 and aquifer 3 which is used as a source of drinking water. All accessible mine workings will be sealed, but it cannot be ruled out that some access will remain open via natural geological structures.

The waste rock pile at the mining site will be reclaimed in situ. It will be covered with a layer of 2 m thickness to reduce ambient dose rates to below 200 nGy/h.

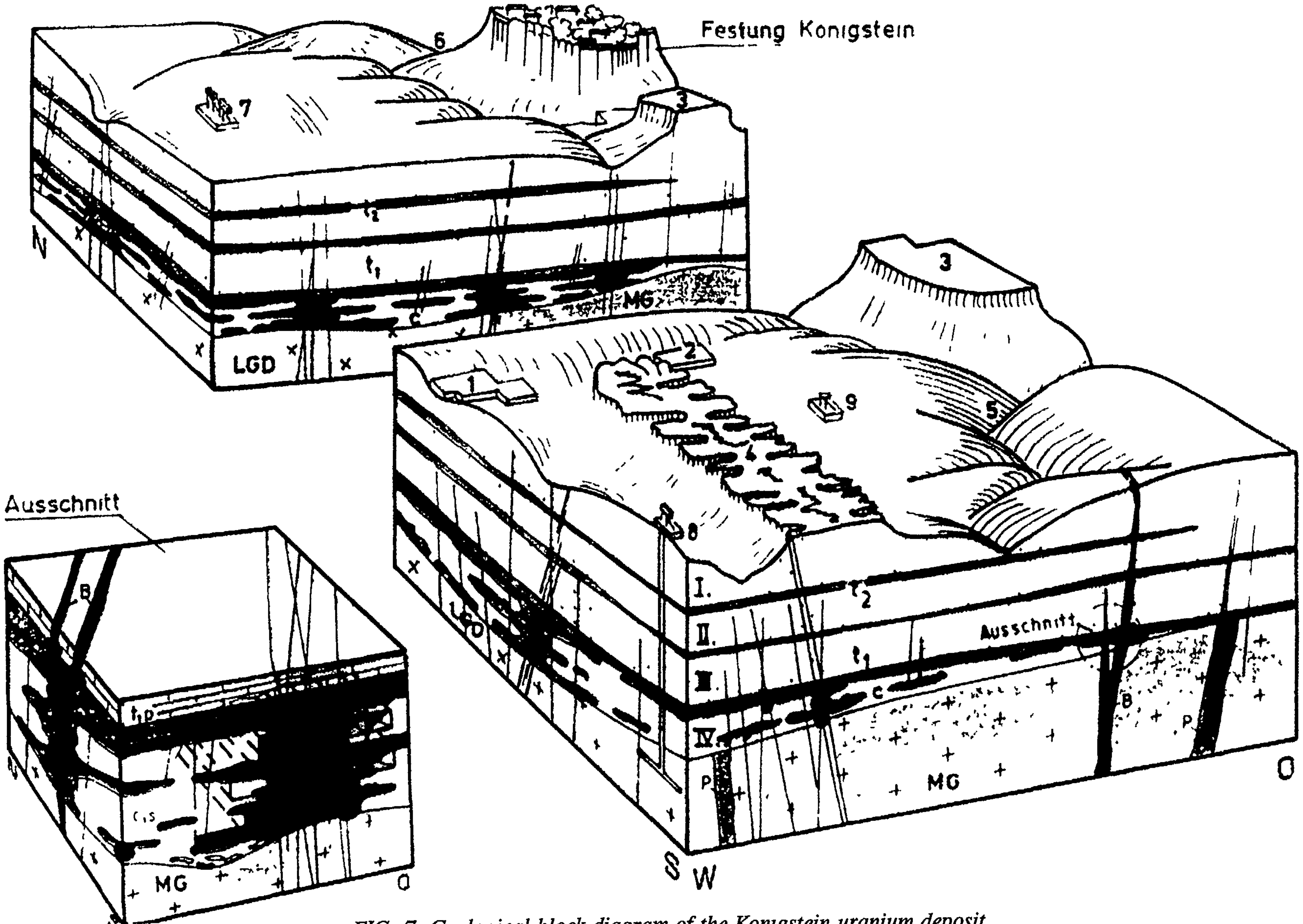

FIG. 7. Geological block diagram of the Konigstein uranium deposit.

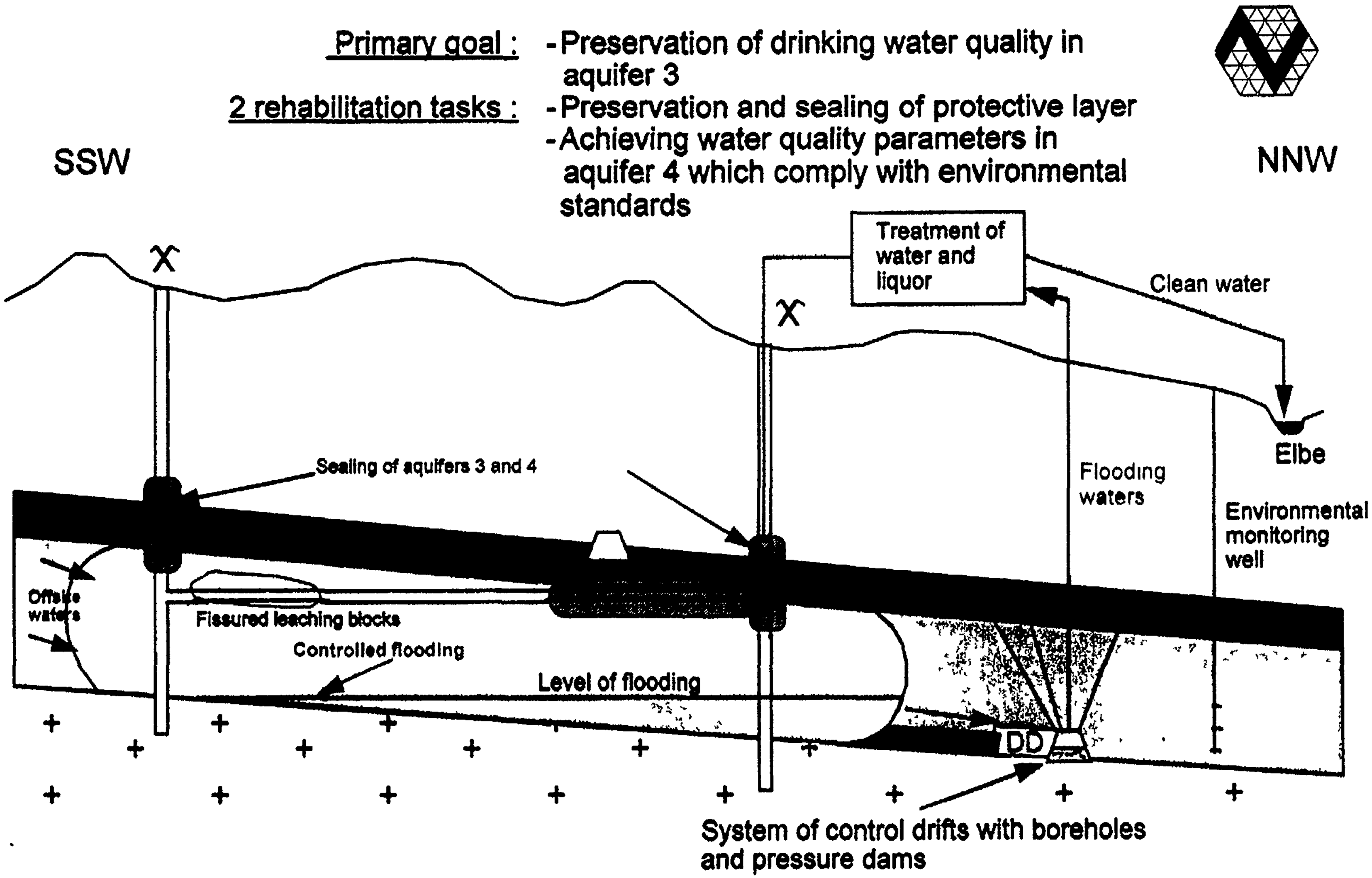

FIG. 8. Rehabilitation at Königstein site.

5. FREITAL (DRESDEN) DISTRICT

At the Dresden-Gittersee coal deposit near Freital, coal has been mined since the Middle Ages. A number of adit systems were put in place for dewatering as for example the 6 km long Elbstolln adit. From 1947 to 1954 and from 1966 to 1989, SDAG Wismut and its predecessor company, respectively, extracted 4 million t coal of 0.09% uranium content. This deposit is to be flooded up to the level of the Elbstolln adit. The waste pile is to be reclaimed in situ. This will prevent any impact on the upper ground water horizon.

At the milling sites, cleanup is concentrated on remediation and rehabilitation of mill tailings impoundments containing approximately 160 million t of fine grained mill tailings which are up to 70 m thick and contain 10 Bq/g Ra. Some of the ponds are situated in worked-out open pits where near surface uranium deposits were mined in Upper Permian sandstones and limes.

At the present time, the major part of seepage is collected and returned to the tailings ponds, so that risks to nearby aquifers can virtually be ruled out. As a preventive measure and in view of final reclamation, a vast hydrogeological investigation programme is under way since 1990 to investigate the surroundings of the impoundments and to prepare for comprehensive modelling of the sites.

At the present state of knowledge, the preferred option would be in situ remediation including removal of the water cover, the gradual covering of emerging beach areas to protect them against erosion and dust generation, the dewatering of the slimes by means of gravity wells and vacuum as well as by additional loads used in combination with geotextiles and textile wicks, and eventually the covering of the dewatered tailings with cohesive soils to reduce rainfall infiltration and radon exhalation.

6. CONCLUSION

Investigations are currently under way at all sites to identify ways how to manage the disposal of radioactively and chemically contaminated soils, building debris, scrap metals and residues from water treatment plants. In these cases, tailings ponds, the worked-out open pit, and waste rock piles might constitute preferred disposal sites. All these activities are accompanied by the establishment of a comprehensive monitoring system.

All these tasks can only be resolved by national and international co-operation. For that purpose, multiple contacts have been established with institutions in Germany and companies in Canada, the U.S., Australia, and France to mention just a few.

At the same time, Wismut is co-operating with communities and concerned citizens to facilitate public acceptance of rehabilitation at a very early stage and to save time in the interest of nearby populations.

THE URANIUM PRODUCTION CONTRACTION PROGRAMME IN THE NORTHBOHEMIAN CRETACEOUS AREA, CZECH REPUBLIC

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Abstract

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 main occurrence area of such a type of deposits, which are connected with the base part of the upper cretaceous sedimentary complex, is the area of the Stráž 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 Stráž block deposits were considered the most prospective sources to cover the long term needs of the Czechoslovak nuclear programme, which was planned on a large scale. The development of the CSUP production activities was very fast in the area of the Stráž block and unfortunately without future considerations. Two uranium deep mines (DH-1, DK-1) were in production and one uranium deep mine (DH-2) was in the stage of preparation at the end of the 1980s. The approximately 6 km^2 ISL production complex was also present beside these classical deep mines. The gradual contraction programme of uranium production in the northbohemian area is connected with the whole Uranium Industry contraction programme and it is caused by:decreasing of the uranium market in the USSR since the end of the 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 of the uranium market apply possibilities abroad (oversupply, great production costs), and re-evaluation of the ecological criterions for the limiting environment load, which is influenced by the uranium production. The contraction programme properly began with the liquidation of the Hamr-2 Mine (DH-2) in the Stráž block at the end of the 1980s. The production of the Krizany Mine was interrupted in 1990 and its liquidation has started. The development of the ISL plant was stopped by government decision in 1991, and its production has been carried on only at the minimum technological level since 1992. A decision about the future of ISL will be made after an evaluation of research and verifying work, which will end in 1994. The last production complex influenced by the contraction programme is the Hamr-l Mine (DH-l), which has been mothballed since mid-1993. The mine production has stopped and only backfilling is performed. A decision about the next future will be made by the government in 1995, after a complete re-evaluation of the whole contraction programme in the Czech Republic.

1. INTRODUCTION

The uranium ore deposits in the Northbohemian Cretaceous were discovered at the beginning of the 1960s. The greatest occurrence of these deposits was checked by the following exploration in the area of the so-called Stráž block. The exploitation development began in the second half of the 1960s. The newly discovered deposits were considered the most prospective uranium source in former Czechoslovakia and they should have replaced the production from classical deposits, such as Pribram, Rozna, Zadni Chodov etc. in Czechoslovakia.

The false strategy was chosen during production development in the area of the Stráž block. The influence of this, together with other outside influences, caused the uranium production contraction also in this newest production area in the Czech Republic.

2. DEPOSIT AREA CHARACTERISTICS

Uranium deposits in the area of the Stráž block belong to the uranium deposits in sandstones. They occur in the base of the Upper Cretaceous sedimentary complex. Its underlier is formed by crystalline rocks of different age. The ore is connected with cenomanian freshwater, mostly agrillaceous sediments and with the lower part of cenomanian marine sandy sediments. The whole thickness of the ore bodies locally exceeds 10 m, but it has some metres in average. The depth of deposits is given by their position in the Stráž block — from about 150 metres in the northern part to about 250 m in the southern part. The Hamr and the Stráž deposits are the largest with about 50% of all resources in the whole Stráž block. The whole area is influenced by the saxon tectonics and the tertiary volcanism.

Hydrogeological relations are very complicated in the Stráž block. Two aquifers are developed in the upper cretaceous sedimentary complex. The lower cenomanian aquifer has an artesian water table and the upper turonian aquifer has a free surface water table. Separation of both aquifers can be defined as semi-confining bed.

A detailed geological description can be found in the report written by Fiedler and Slezák for the IAEA TCM on In situ leaching of Uranium, which was held in Vienna in October 1992.

3. PRODUCTION DEVELOPMENT AND CONTRACTION

The uranium production development in the Stráž block began in the middle of the 1960s, although no sufficient results from the exploration stages had been done at that time. The development of the ISL technology on the Stráž deposit and the classical deep mining technology on the Hamr deposit started.

It was already evident at the beginning of the 1970s, that the parallel extensive development of both production methods close to each other was wrong. However, in the interest of a maximizing uranium production no corrections to this development were done and production continued with the same intensity.

Technical measures to ease the negative influences of this wrong conception, such as a hydraulic barrier and a protective draining system of the Hamr mine, were realized only after delays. For more detailed information about the coexistence see the report written by Fiedler and Slezák for the IAEA TCM on In situ leaching of Uranium, which was held in Vienna in October 1992.

The second deep mine in this area, the Krizany mine, was opened on the Brevniste deposit during the 1970s. The third mine in this area and the second mine on the Hamr deposit was opened during the 1980s.

Maximal uranium production was reached in the middle of the 1980s by the parallel production of the two deep mines and the ISL plant. Uranium production contraction began in the area of the Stráž block at the end of the 1980s. The Hamr mine Nr. 2 (DH-2) was closed and liquidated first in 1988. The Krizany mine production was stopped in 1990 and is liquidated at present. The ISL production has been practiced only at the lowest technological level and without enlargement since 1991. The production of the Hamr mine Nr. 1 was stopped in the middle of 1993, and this mine is being mothballed.

4. REASONS FOR THE URANIUM PRODUCTION CONTRACTION IN THE STRÁŽ BLOCK

The reasons for the uranium production contraction can be divided into two categories:

1) Lowered uranium demand and re-evaluation of the uranium industry from the strategic branch into the normal industrial branch.

Lowered uranium demand resulting from the reduction of the nuclear programme in the Czech Republic, ending the uranium deliveries to the USSR and splitting of Czechoslovakia, since Slovakia uses no Czech uranium. A re-evaluation of the strategical importance of the uranium industry resulted from the fall of the totalitarian regimes in eastern and central Europe.

2) Change of the ecological criterions for the uranium production evaluation and the profitability of the present uranium production from the Stráž block.

This second category reflects worse uranium production development conception in the Stráž block and patronizing attitudes to the production influences on the environment. The great financial needs will be required for the liquidation of these influences.

5. A BRIEF PRODUCTION FACILITIES OVERVIEW

5.1. The ISL plant

The ISL production area is about 6 km^2 at present, with about 7000 technological wells. The diluted sulfirid acid solution is used as a lixiviant. 330 million m^3 of leaching solutions were circulated in the ISL area in the period from 1967 to 1993. 13 500 metric tonnes of uranium were produced during that time. 4 million metric tonnes of H_2SO_4, 0.3 millon metric tonnes of HNO_3, 0.1 millon metric tonnes of NH_4 and 0.03 millon metric tonnes of HF were also used underground for the uranium production.

The main problem with this production method is the migration of leaching solutions out of the production area. The overbalance regime of ISL with a greater amount of injected volumes than produced volumes and the proximity of the deep mine caused the influence of the underground water in the area of 28 km^2 and the whole volume of 190 million m^3.

ISL is in the special technological regime now. The exploration works will be evaluated until the end of 1994 and the government will make a decision about the future of ISL based on those results. The first measure, which is already realized for the improvement.of the present situation, is building a station for the liquidation of technological leaching solutions. It will have a capacity of 2.5 million m^3 per year.

Liquidation of ISL will be a long term and expensive matter and it will produce about 2 000 metric tonnes during the leaching solutions liquidation until 2005.

5.2. The Hamr mine Nr. 1

The Hamr Mine Nr. 1 is situated in the northern part of the Hamr deposit. Subhorizontally deposited ore bodies with a thickness of 2 to 10 m were mined out using a room and pillar method. The mined out space is backfilled using a special concrete backfilling.

The whole amount of about 500 l/sec of mine water is pumped from the mine, of which about 350 l/sec are pumped from the protection draining system. About 250 l/sec of it are acidic mine water injected into the Stráž hydraulic barrier, which is an artificial pressure water-shed between the Hamr mine and the ISL plant.

About 10 700 metric tonnes of uranium with an average grade of 0.110% have been produced from the Hamr mine from 1971 until now. About 5 000 metric tonnes of U can be produced without greater problems in the present opened mine field. Any production over this amount should require increased investment costs.

The Hamr mine Nr. 1 has a great production capacity for about 700 metric tonnes of U per year. Capital costs increase when the production is low (low demand) and then the production is more expensive. This is the main reason for the present mothballing of the Hamr mine. The Government will make a decision about the future of the mine in 1995.

5.3. The Krizny mine

The Krizany mine is flooded now and the liquidation works have stopped, because of the possible sale of the surface buildings to a private owner. A description will be given in a separate paper during this Technical Committee Meeting.

5.4. The Hamr mine Nr. 2

The resources in the southern part of the Hamr deposit should have been exploited by the Hamr mine Nr.2. The first attempt to open this part of the deposit was done by sinking the shaft Nr. 9P in the middle of the 1960s. The opening was stopped because of uncontrollable underground water inflow during the shaft sinking, and other development of the underground mining was transferred to Hamr mine Nr. 1.

The next attempt to open the mine was started at the beginning of the 1980s. The two shafts — Nr. 6 and Nr. 7 were sunk and horizontal work in the underlying rocks was done until 1988. The whole volume of the mined out rocks was about 42 000 m^3.

The underground workings of the Hamr mine Nr. 2 were only flooded during the liquidation works. The surface buildings liquidation is being finished now. The backfilling of both shafts is needed before the finishing of the liquidation works to prevent communication between the cenomanian and the turonian aquifers.

We can state that Hamr mine Nr. 2 was practically undrainable or the costs spent for the drainage would exceed an unacceptable level. This proves the conceptionless uranium production development in the Stráž block.

5.5. The Stráž mill and the setting pit

The Stráž mill and the setting pit are the necessary part of the deep mining. Both are mothballed now. Incidental liquidation of the Stráž mill area would be a very expensive matter because it is a very large object. Therefore an endeavor is being made to find another possible use for this area. One real possibility for the long term use is the technology of the ISL solutions decontaminations.

The setting pit represents another problem, which should be solved in the frame of the contraction programme. It has been in use since 1980 and its planned capacity was about 50 million metric tonnes of technological muds. About 13 million metric tonnes are deposited there now. Interruption of the deep mine production caused the problems, especially in the second stage of the setting pit, because it was projected for the fast colmatage of the bottom, in consequence of the high intensity of muds floating. In a consequence of the imperfect bottom packing, ground water influence is the main problem now. It will be a long term and very expensive matter to stabilize the setting pit without negatively influencing the environment. The development of the setting pit water liquidation technology and the development of the contaminated ground water cleaning technology are the main problems. There are more than 10 million m^3 of contaminated water.

6. CONCLUSIONS

The Stráž block uranium deposits present the greatest concentration of the uranium resources in the Czech Republic. They are the low grade ores averaging about 0.1% of uranium. Their exploitation is made difficult by the complicated hydrogeological conditions and the scattering of the production facilities as a result of the poor conception of the production developments planning.

The uranium production contraction in the Northbohemian cretaceous since the end of the 1980s fits in with the whole production contraction in the Czech Republic and other post-communist states. The contraction pace, however, has to be done in such a way, as not to create other damage, by ill-considerated fast progress. The acceptable costs of the contraction programme to the Czech economy are another consideration. Concrete assistance of the western countries has not been sufficient yet, although it was proclaimed. The sale of the completed uranium production should be the greatest assistance, because the funds obtained could be used for the optimal form of the uranium production contraction, together with social influences.

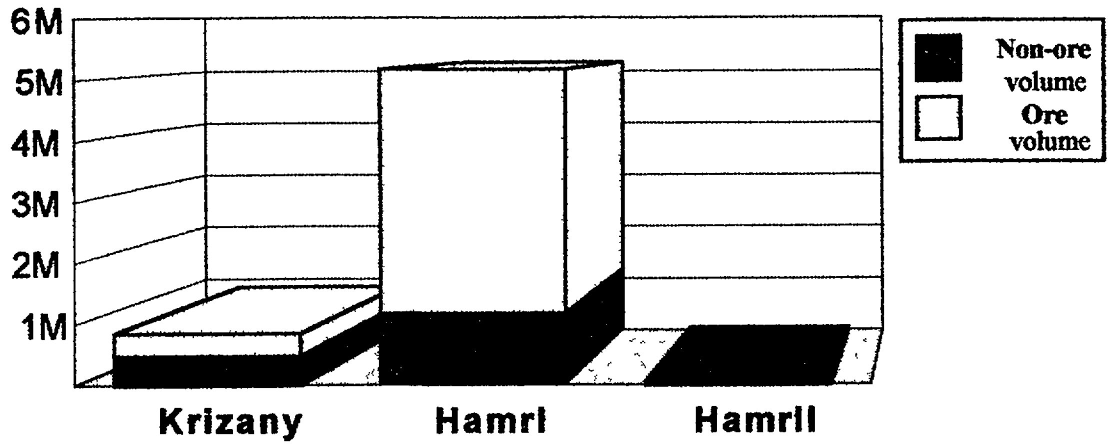

FIG. 1. Mined out volumes in Northbohemian Cretaceous (total volume in m^3).

TABLE I. MINED OUT VOLUMES IN NORTHBOHEMIAN CRETACEOUS

Mine name	Nr.	Shafts length	Volume	Other non-ore volume	Total non-ore volume	Ore volume	Total volume	Tonnage	U in ore
		m	m^3	m^3	m^3	m^3	m^3	kt	kt
Krizany	2	549.8	16 093	449 649	465 742	372 423	838 165	1 178	1.06
Hamr I	4	956.2	30 597	1 133 882	1 164 479	3 994 806	5 159 285	9 600.8	10.66
Hamr II	2	613	34 800	7 200	42 000	0	42 000	0	-

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RELEVANT ASPECTS TO ENUSA'S PROGRAMME TO CLOSE THE URANIUM MINING AND MILLING FACILITY OF "LA HABA"/BADAJOZ (SPAIN)

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Abstract

ENUSA's "LA HABA"/Badajoz uranium mine and mill is located in the province of Badajoz in southwest Spain, 11 km from La Haba. The mine was in operation from 1983 to 1990. Decommissioning and rehabilitation of the facilities, which was started in 1992, is to be completed in 1994. The present paper describes the experience of planning and executing this programme taking into account site characteristics, nature of the facilities, design objectives and economics.

FIG. 1. Uranium facilities in Spain.

1. INTRODUCTION

The Empresa Nacional del Uranio, S.A. (ENUSA), is a Spanish company created in 1972. ENUSA provides products and services related to the front end of the nuclear fuel cycle.

Uranium mining and production activities have been carried out by ENUSA since 1973 in the area of Ciudad Rodrigo (Fig. 1), province of Salamanca, they were based on open pit mining, heap leaching and a hydrometallurgical plant (plant ELEFANTE) for obtaining uranium concentrates from the pregnant liquids. During 1993 was stopped the Plant ELEFANTE and was started up a new plant (plant QUERCUS) with dynamic leaching. The nominal capacity of the new plant is 950 t U_3O_8/year, nowadays because the low prices of uranium, the facility is running to a production rate of 300 t U_3O_8/year.

In the near future ENUSA has to prepare both, the restoration plan for the work out open pits, by backfilling with wastes rock material and overburden, and the decommissioning programme activities for the "Plant ELEFANTE", the heaps leaching depleted and the tailings dams. All the studies will be submitted for approval to the Spanish Nuclear Safety Council.

Similarly ENUSA was operating since 1983 in the area of Don Benito, province of Badajoz, an uranium facility based on open pit mining and experimental plant LOBO-G. These activities were stopped during the year 1990.

ENUSA got the approval for the restoration of the work out open pits in Don Benito area during the year 1992 and at the present ENUSA is performing this task. The studies for the decommissioning of the Plant LOBO-G the heap leaching and the tailings dam will be completed on May 1994.

The purpose of this article is to present information on ENUSA's experience in the close-out of the uranium mining and milling facility of "LA HABA"/Badajoz.

2. SITE CHARACTERISTICS

The mining and milling facilities are in the province of Badajoz, on the southwest of Spain at 11 km. from the urban center of La Haba. The site covers an area of 1×10^6 m^2 and the distance to the Ortiga river is about 1 500 m.

The soil contains granite and clay and its permeability is very low.

TABLE I. SITE CHARACTERISTICS

SITE CHARACTERISTICS	
Annual mean temperature	13°C
Maximum annual temperature	42°C
Minimum annual temperature	-4°C
Annual average precipitation	450 mm
Mean annual evaporation	1200 mm
Seismic classification (tailings dam)	horizontal: 0.15 g vertical: 0.10 g

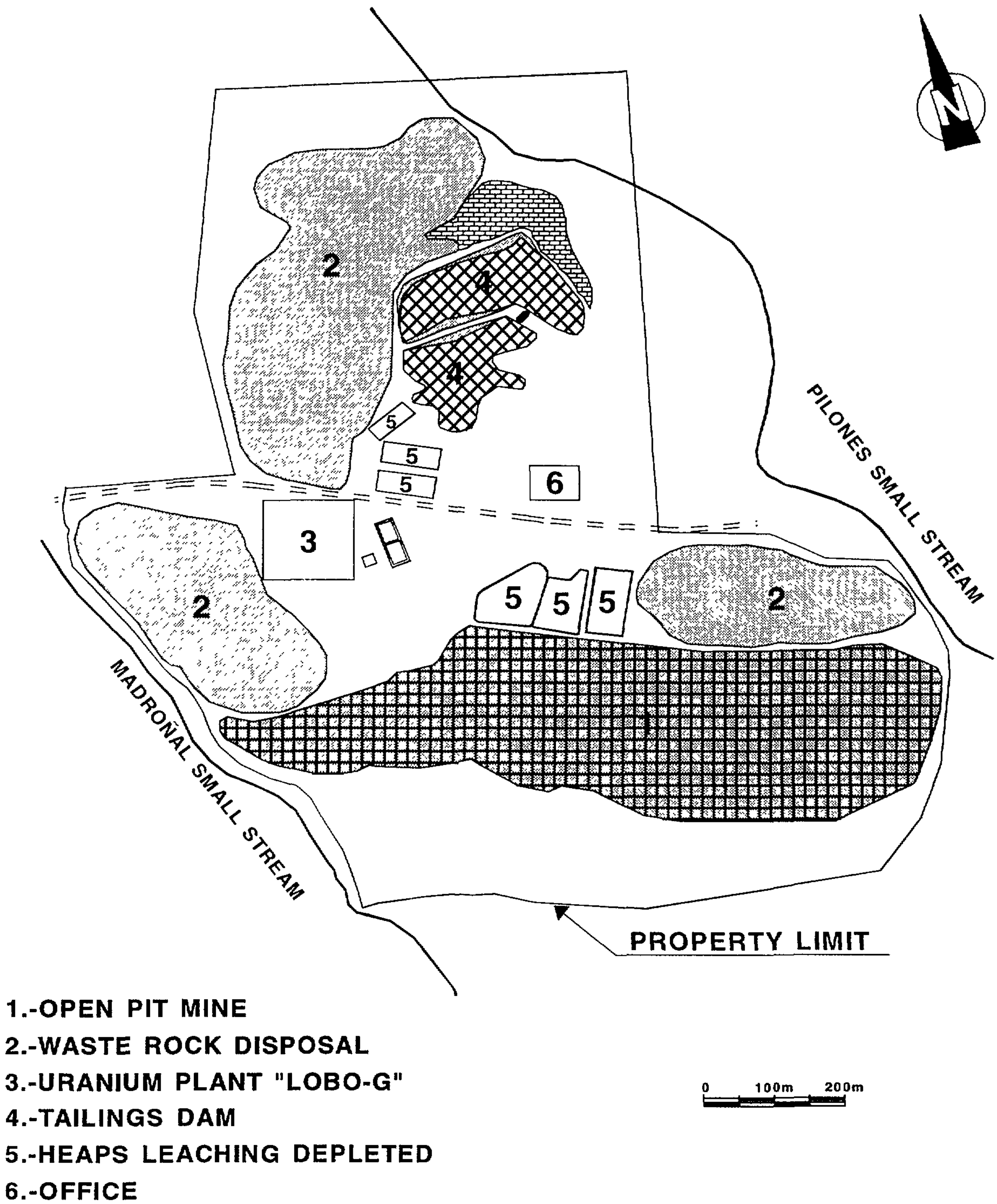

FIG. 2. Uranium mine and plant "L Haba" Badajoz (Spain). Layout of facilities.

The climate of the area is characterized by low precipitation, abundant sunshine and moderate to high temperatures with large diurnal and annual ranges (Table I).

The annual mean temperature daily average is 13 °C with a maximum of 42 °C and a minimum of -4 °C. The mean in the diurnal range is 14 °C.

The annual average precipitation is 450 mm. The mean annual evaporation is 1 200 mm. Most of the precipitation has place during the fall and winter seasons. Most of the evaporation occurs from May through September.

The seismic classification of the zone is level VII.6 (M.S.K.) and the horizontal acceleration to be applied to seismic structures (Tailings dam) were 0.15 g horizontal and 0.10 g vertical.

3. DESCRIPTION OF THE FACILITIES TO CLOSURE

At the time when the running activities were stopped (on March 1990) the facilities and waste materials to manage in the stage of the permanent closure were as follows (Fig. 2):

a) Open pit mine
The ore from these deposits was processed in the FUA Plant in Andujar during the 70's and in the LOBO Plant during the 80s.

The extension of the mine is about 200 000 m^2 and the waste rocks disposal related to the mine has about 9×10^6 tonnes of waste.

b) Plant LOBO-G
In this experimental Plant, the ore with grade over 1 000 ppm of U_3O_8, was separated granulometrically into a coarse fraction, which together with the marginal ore was treated by heap leaching, and a fine fraction, which was treated by leaching in agitated tanks, countercurrent washing in cyclones and resin in pulp process (RIP), before incorporating the pregnant liquors in the solvent extraction stage.

c) Heaps leaching
The number of heaps built during the operation of the facilities were 6 and the amount of mineral depleted was about 3.5×105 tonnes.

d) Tailings dam
The tailings dam (Fig. 3) was built according with the Regulatory Guide 3.11 of the Nuclear Regulatory Commission (U.S.A.) and the National Codes; its main characteristics are as follows:

Cell area	37 000 m^2
Capacity	107 000 m^3
Height	20 m
Sideslope inclination	3/1 and 2.5/1

4. STRATEGY AND OPTIONS

The options considered for the closure of the facilities were as follows (Fig. 4):

*** Waste rock disposal**

- Strip mining
- Closure in open pit mine
- Stabilizing and in situ closure

*** Heaps leaching depleted**

- Closure in open pit mine or tailings dam
- Stabilizing and in situ closure

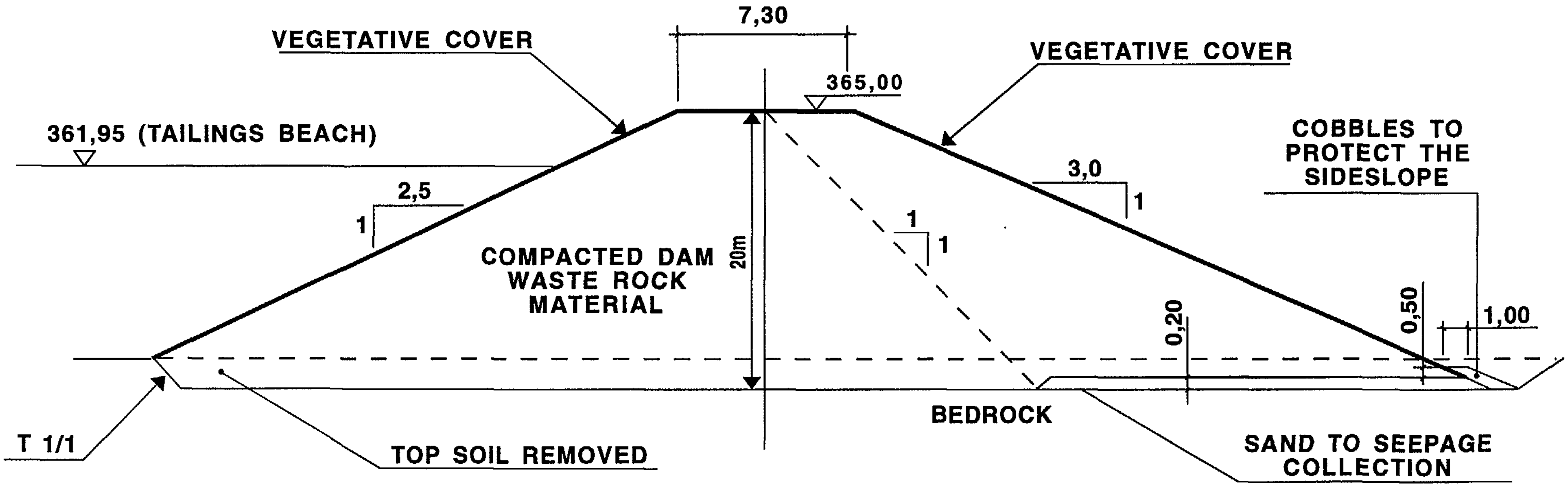

FIG. 3. Tailings dam section.

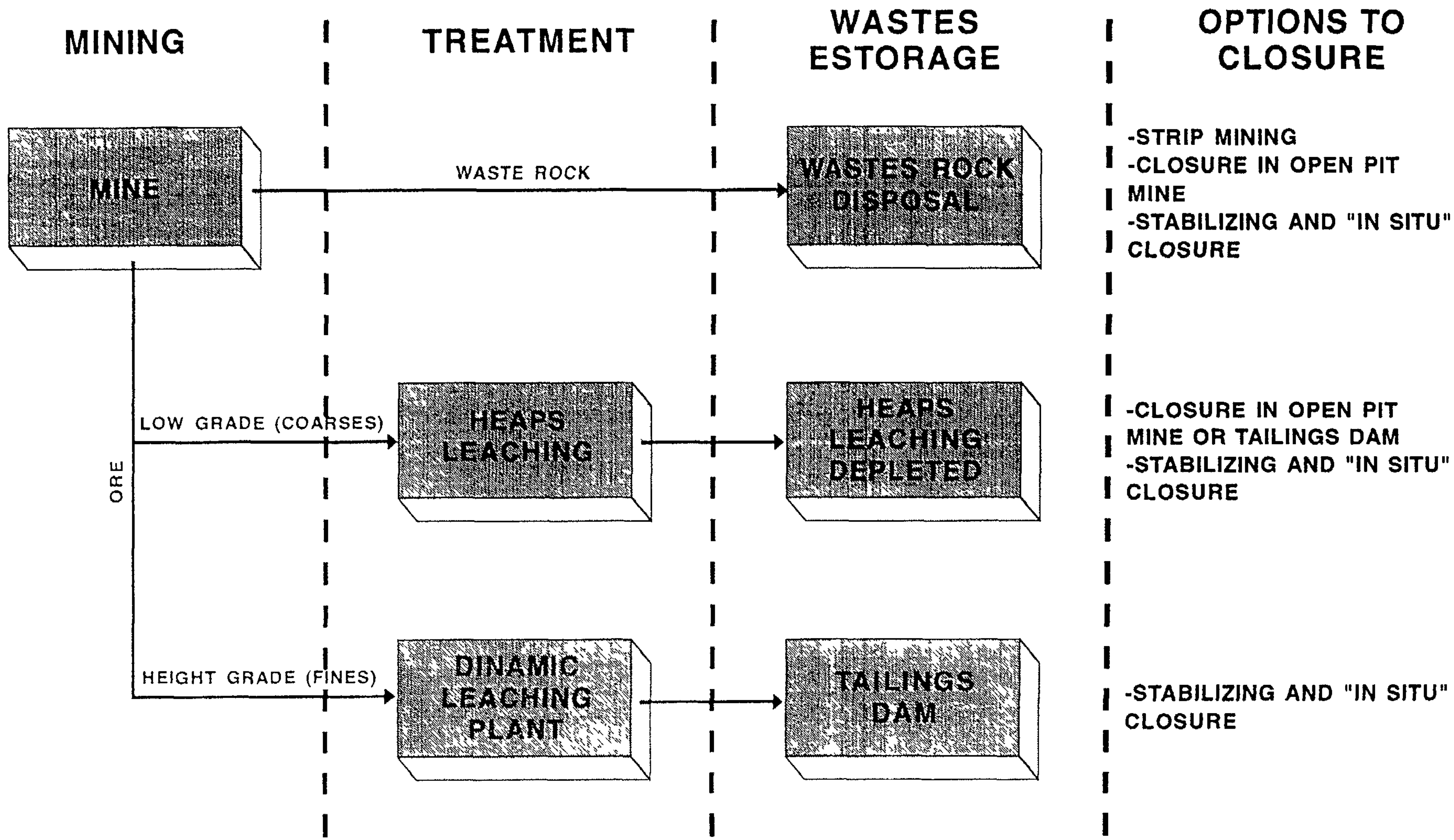

FIG. 4. Management of wastes in uranium facilities.

*** Tailings dam**

- Stabilizing and in situ closure
- Multicomponent cover
- Single component cover

*** LOBO-G plant**

- Equipment decontamination
- Equipment disassembling
- Soil cleanup
- Transport and storage of the wastes (equipment and debris) to the tailings dam

TABLE II. DESIGN OBJECTIVES

Parameter	**Objectives**
Radiological impact	After closure must be similar to the radiation background of the zone. During the closure the radiation doses received by the workers and the public will be controlled according to the ICRP recommendations.
Radon control	The activity of the radon flux after the closure must be less than 1 $Bq/m^2/s$ averaged over an area of 10×10 m.
Design life	Remain stable for at least 200 years remain stable for 1000 years to the extent of contaminated materials by wind and water.
Dispersion control	Prevent dispersion of contaminated materials by wind and water.
Water seepage	Minimize water seepage generation from infiltration through the cover.
Maintenance	Reduce the need for long term maintenance. Establish a period of 5 – 10 years surveillance programme.
Liquid waste removal	This is the first operation for the tailings dam closure.

5. DESIGN OBJECTIVES

The design objectives have been established according with the local and national regulations, and the requirements of the community affected by the facility. Table II indicates the parameters and the objectives of the design which are as follow:

a) Radiological Impact

The radiological impact of the facility after the closure must be similar to the radiation background of the zone.

During the closure operations the radiation doses received by the workers and the public will be controlled according with the ICRP recommendations.

b) Radon control

The activity of the Radon flux after the closure must be less than 1 $Bq/m^2/s$ average over an area of 10 × 10 m

c) Design life

Remain stable for at least 200 years and 1000 years to the extent reasonably achievable d) Dispersion control Prevent dispersion of contaminated materials by wind and water. Prevent intrusion by human and animals

e) Water seepage Minimize water seepage generation from infiltration through the cover

f) Maintenance

Reduce the need for long term maintenance. Establish a period of 5 ÷ 10 years surveillance programme after the closure to assure that the design criteria have been achieved.

g) Liquid waste removal

This is 1st. operation for the tailings dam closure.

6. SITUATION OF THE CLOSURE PROGRAMS

6.1. Waste rock disposal

A part of the Waste Rock Disposal (5 × 10^6 t) has been stabilized in situ, the other part (4 × 10^6 t) has been transported and used for backfilling of the open pit mine.

6.2. Heaps leaching depleted

The heaps with low ore grade (less than 700 ppm of U_3O_8) have been taken to the open pit mine and the others have been carried to the tailing dam.

6.3. Plant

All the scrap components coming from both the equipment disassembling and the soil clean up will be taken to the tailings dam.

6.4. Tailings dam

The closure of the tailings dam is in the phase of design.

The wastes to be stored in the dam will be as follows:

- 100 000 tonnes of tailings

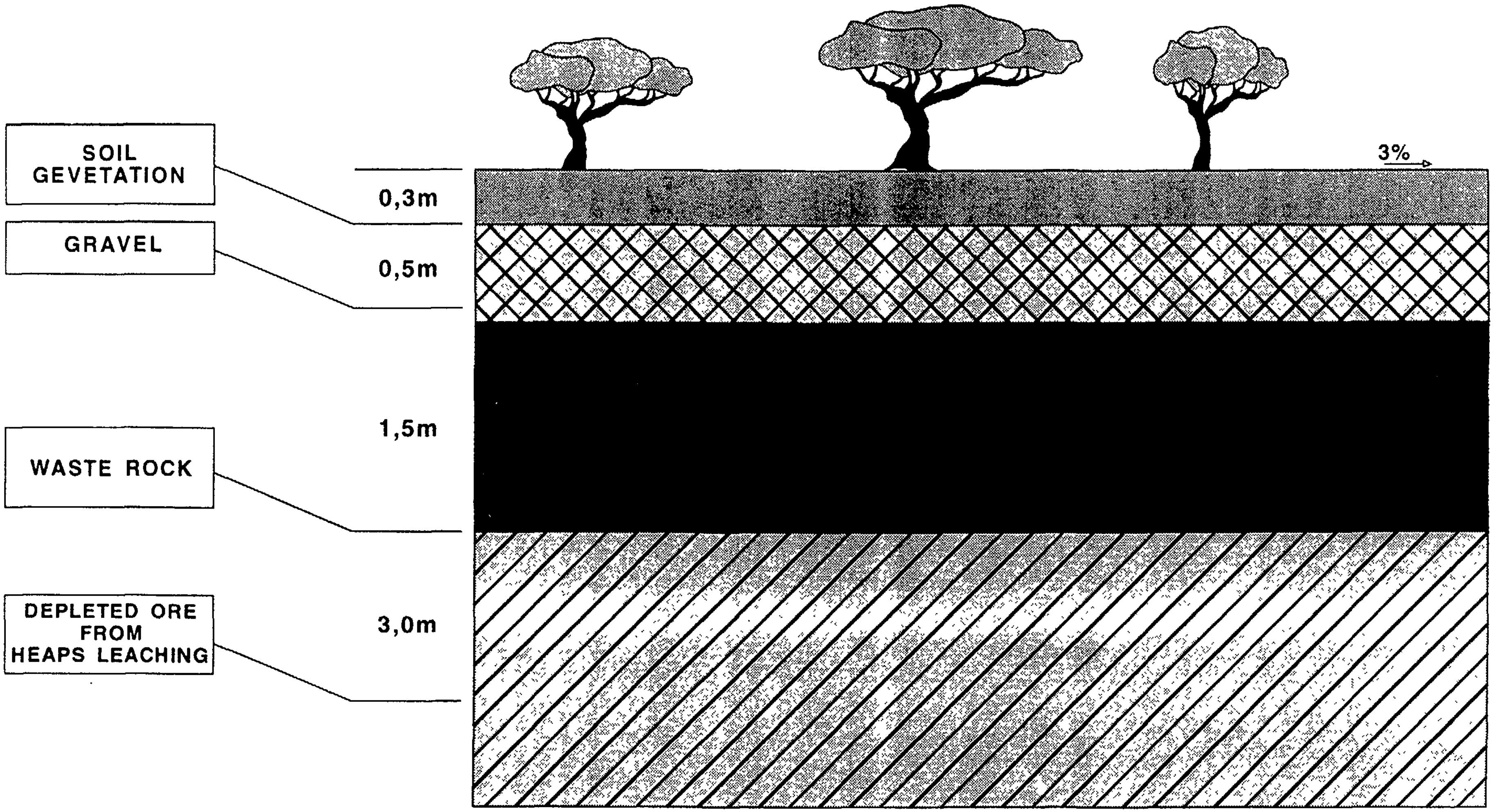

FIG. 5. *Multicomponent cover.*

- 150 000 tonnes from the heaps leaching depleted
- 20 000 m^3 scrap material from the plant disassembling

For the tailings dam cover we are considering two alternatives. The first one includes a multicomponent cover ant the second one includes one component cover.

The multicomponent cover incorporates the following components (Fig. 5):

- A layer of 3.00 m. thickness including depleted ore from the heaps leaching;

- An infiltration and radon barrier 1.50 m thickness consisting in waste rock from the mine. This material contains about 30% of clay;

- A layer of about 0.50 m thickness with gravel to drain water;

- The top soil cover with vegetation;

The one component cover includes a layer of 3.00 m thickness with waste rock material taken from the earthen part of the mine. This material is a mix of all the components of the multicomponent cover alternative.

7. ECONOMICAL ASPECTS

The closure activities both engineering and work shop are carried out by ENUSA'S personal.

The estimated costs in U.S.A. dollars for the closure operation are listed below.

a. Wastes rock disposal

In situ stabilizing . . . . 0.5 \$/ton

Transport & backfilling open pit mine . . . . 1.0 \$/ton

Restoration and revegetation . . . . 1.0 \$/m^2

b. Plant disassembling and cleanup of the ground (total cost) . . . . 5 × 105 \$

c. Tailings dam closure (total cost) . . . . 1 × 10^6\$

d. Engineering, including environmental impact
Project statement (total cost) . . . . 5 × 10^5\$

e. Forced evaporation of liquid effluents over the catchment area of the
tailings dam . . . . 1.5 \$/m^3

EXPLORATION, EXPLOITATION AND CLOSURE OF THE KRIŽANY MINE (THE BREVNISTE DEPOSIT) IN THE NORTHBOHEMIAN CRETACEOUS, CZECH REPUBLIC

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Abstract

The Križany Mine was the last newly opened uranium mine in former Czechoslovakia. This mine opened the Brevniste deposit, which was found by the hydrogeological borehole SZ-10 in 1966. Exploration work was done by the Uranium Industry Geological Exploration Company until 1980. The building of shaft No. 4 started in August 1973 and was finished in September 1975. The second shaft on this deposit, shaft No. 5, was built from September 1973 until September 1976. Both shafts were built with a diameter of 4.8 m and with a depth of more than 280 m. The first exploitation rooms were opened in September 1983 and backfilling of the mined-out rooms started in November 1984. Production finished on 30 April 1990 and backfilling in September of the same year. The production of the mine was about 1 180 000 t of uranium ore (containing more than 1 060 t of uranium) between 1983 and 1990. The losses during the milling process were between 5 and 20% and they are not known exactly because of mixing ores from the different mines. The closing of the Križany Mine was based on the decision of the Czechoslovak Federal Government (No. 94/1989). This dealt with decreasing the financial losses in the Uranium Industry in 1990 and later, using a contraction programme. This paper is based on "The Final Report about the Results of Exploration and Exploitation on the Brevniste Uranium Ores Deposit (the Križany Mine) in the Northbohemian Cretaceous", which was done by the Geological Department of DIAMO's division TUU in Stráž pod Ralskem at the end of 1993.

1. INTRODUCTION

The Brevniste deposit is one of deposits in the Northbohemian cretaceous uranium ores area. This area is located about 70 km north-north-east of Prague. The main part of this area is the Stráž block, which was the most explored and prospective area, lying between the cities of Ceska Lipa and Liberec. The Stráž block, with an area of about 220 km^2, is tectonically limited by faults: in the north-west by the Stráž fault, against the deeply sunken cretaceous Tlustec block, in the north-east by the Lugian fault against the crystalline rocks of the Jested complex, in the south-east by a belt of neovolcanic dykes called "the Devil's Walls" and in the south-west by the Hradcany fault. The sedimentary upper cretaceous sandy rocks are underlain by a complex of lower and middle proterozoic (?lower paleozoic) metamorphic rocks with paleozoic granites. Upper paleozoic (carboniferous) sediments occur in some southern parts of the Stráž block under the createaceous sediment.

The cenomanian fresh water sediments start the cretaceous sedimentation and are followed by brackish sediments. The main part of the cenomanian sedimentation belongs to the sandy marine sediments. The cenomanian sediments are the most important source of uranium ores, especially the brackish and lower part of the marine sediments. The cenomanian sediments are overlain by the lower turonian impervious (semi-pervious) sediments, which separate the cenomanian and middle turonian aquifers. The middle turonian sediments finish the cretaceous sedimentation in the Stráž block and they reach up to the surface.

The deposit lies on the border between the Ceska Lipa and Liberec districts. It adjoins the Križany deposit to the north-east, the Osecna-Kotel deposit to the south-east and the Hamr deposit to the south-west. The north-western border is formed by the Stráž fault. The clime of the deposit has 13.66 km^2.

2. SURFACE EXPLORATION

The deposit was found by hydrogeological borehole SZ-10 in 1966 after the unsuccessful drilling exploration on a net of 800 to 800 m in 1965. This exploration was performed by the full-core boreholes. The next step of exploration was done on a net of 400 to 400 m with coring only in the cenomanian interval. The 100 to 200 m net was realized without coring. The detailed exploration works were done in the 50 to 200 m net with increased core yield from the ore interval. 655 exploration boreholes were drilled during 1964 to 1991. Also well-logging played a very important role during this exploration, because there was no need to take core from every borehole and every interval.

The surficial structural geological exploration was the next step of exploration. It was done in many scales from 1:10 000 to 1:1000. Only geophysical methods were used until 1974. Geological mapping was also performed after 1974 in combination with geophysical works. 183 surficial ditches were dug in the area of the deposit after 1974.

3. THE MINE OPENING AND EXPLOITATION

The Križany Mine arose as an independent organizational unit with the framework of the former Hamr Uranium Mines after 1 January 1979. Exploitation was licensed in the clime named Križany II in 1978. Building of the surface facilities started at the end of 1973. The sinking of the shaft #4 began in August 1973 and continued until September 1975, when it was finished at a depth of 281.3 m. The sinking of shaft #5 passed from September 1973 till September 1976 and was finished at a depth of 268.5 m. Both shafts and the whole mine were called Križany, because the shafts lie in the area of Križany Village. (But the explored deposit is named Brevniste, because it is lying in the area of the village Brevniste.) Landing bottoms of the shafts were done from October 1975 until October 1976. The next opening works, such as gates, service rooms etc. in the underlying rocks have been done since the end of 1976.

The ore horizon was opened by slanting gates or by chutes since 1982 and the first mining rooms were exploited in September 1983. The so-called "three rooms" mining system was used at the beginning of the production. The mined block was divided into rooms (belts) with a width of 5 m. Every third room (the so-called primary room) was mined out in a first step Mining of a next room (the so-called secondary room) continued next to the mined out space in a 10 m wide pillar after the backfilling of the primary room. The remaining 5-m-wide pillar was mined out as the so-called terciary room. The block was finished and closed after backfilling the whole mined out space. This system was changed into the so called "four rooms" mining system, which is more useful with less consumption of needed materials. The block was also divided into belts with a width of 5 m, but the primary room was every fourth room. The second primary room was opened with a width of 5 m in the middle of the 15-m-wide remaining pillar. The last step was exploitation of the remaining 5-m-wide pillars as the terciary rooms. The height of rooms in both systems was driven according to the thickness of the ore body. The full backfilling was used in all blocks to save the impermeability of the lower turonian isolating layer. The liquid concrete backfilling was dropped into the mine through the technological well from the backfilling centre placed on the surface, using moveable pipelines to reach all the room in the whole mine. All the mining works were done using a blasting work.

The blasted ore was transported to ore chutes, using a German loader GHH MAN-LF4. The ore from chutes was showered into the mine cars with volume of 1 m^3 and carried to the shaft #4, where it was transported to the surface.

Used extraction technology was based on a sulfuric acid lixiviation. The first step was the milling of the ores. The ore was divided into two fractions — sand fraction a fine-grained fraction. They were processed separately. Ammonia diuranate is the final product of the extraction technology.

Wastes from the technology were deposited in the setting pit near the mill. Ore production finished on 31 April 1990.

4. LIQUIDATION OF THE MINE

Liquidation of the Križany Mine was based on the decision of the Czechoslovak Federal Government (No. 94/1989) This dealt with decreasing the financial losses in the Uranium Industry in 1990 and later, using a contraction programme.

Liquidation of the mine has been divided into three stages:

Stage 1. Liquidation of the underground during 1990
All mining rooms and the critical parts of gates (especially on crossings with tectonics) were backfilled during this time. All material, which should pollute the water (especially oil materials) were moved out of the mine.

Stage 2. Liquidation of unusable surface property, technical reclamation of the heap, building of the pumping centre for the Hamr Mine water supply and liquidation of the hydrogeological and exploration boreholes in the area of the Križany mine.

Stage 3. The last step of liquidation has only been done to the project stage whilst waiting for the government's decision about the sale of the mine property. No decision has been made yet.

TABLE I. URANIUM PRODUCTION FROM KRIŽANY MINE (WITHOUT PROCESSING LOSSES).

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990
U in tonnes	26.6	59.2	139.3	164.0	161.8	165.1	158.5	139.6	46.0

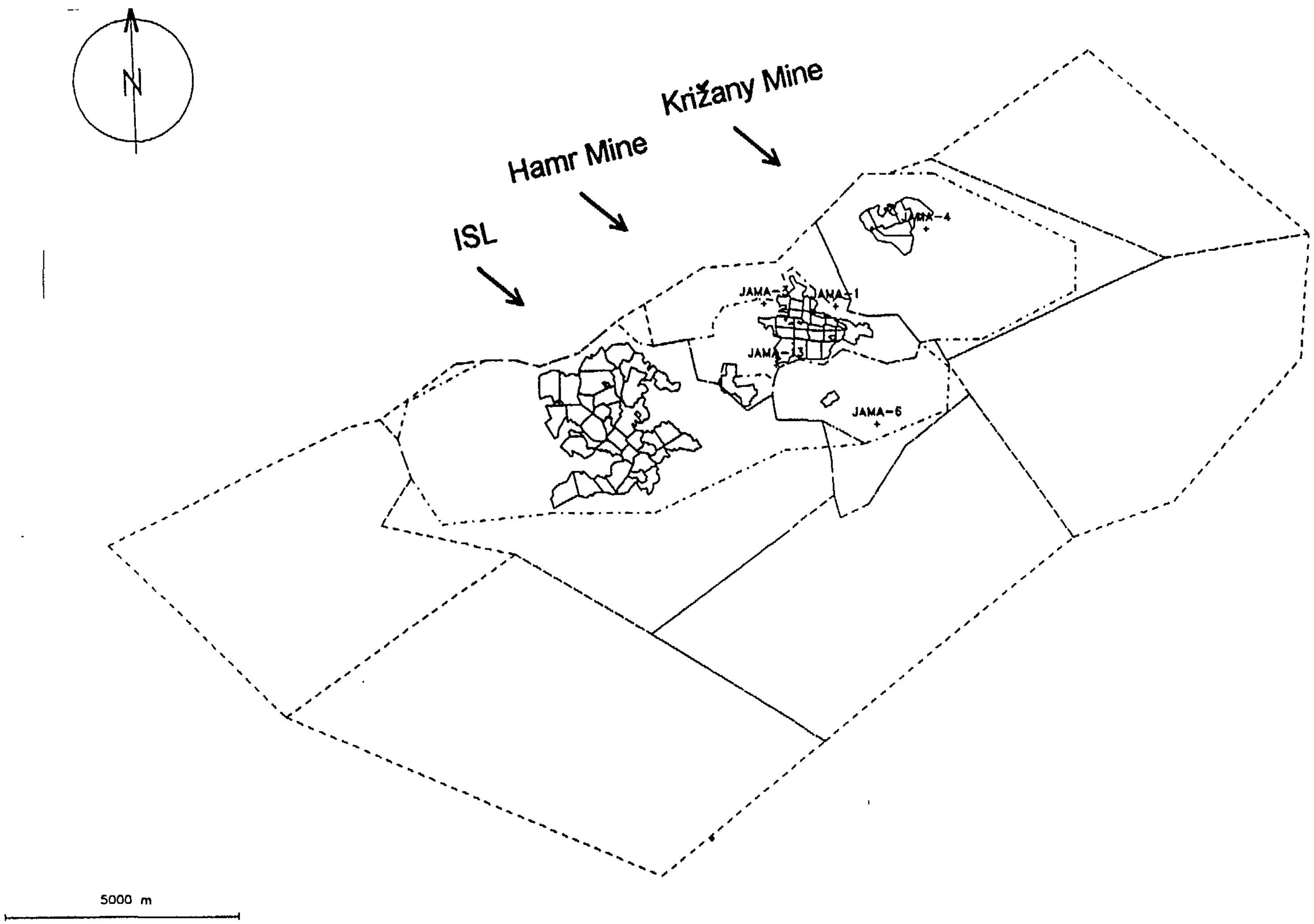

FIG. 1. Schematic map of the Stráž block.

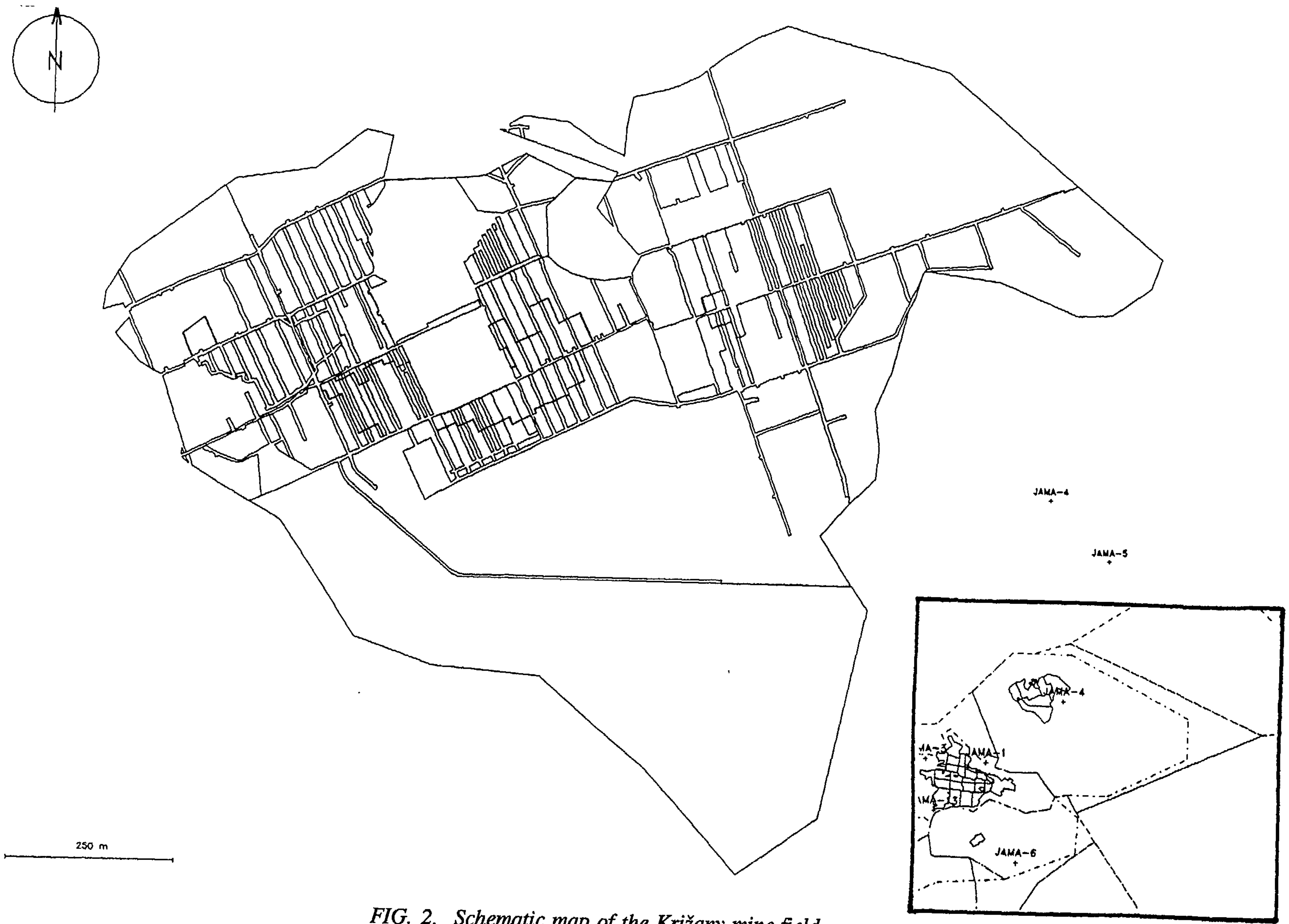

FIG. 2. *Schematic map of the Križany mine field.*

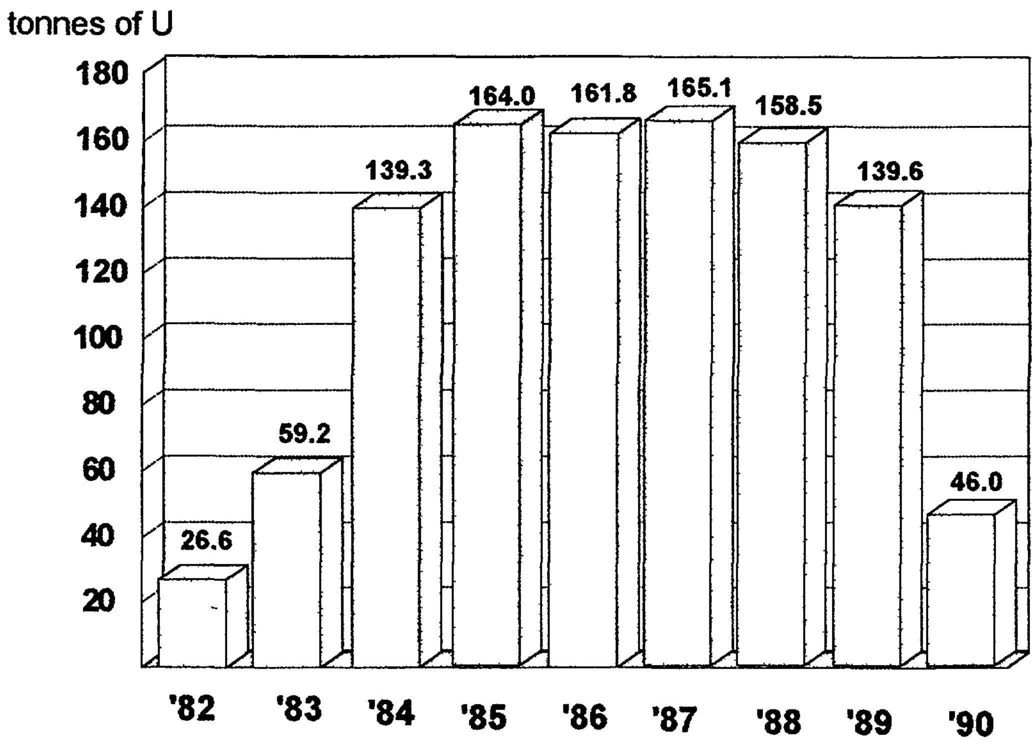

FIG. 3. Uranium production from Križany mine.

PROGRAMME FOR THE CLOSEOUT OF THE ŽIROVSKI VRH URANIUM ORE MINE (REPUBLIC OF SLOVENIA)

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Abstract

In the Republic of Slovenia, the Žirovski vrh Uranium Ore Mine stopped its regular operation in 1990 by the decision of the Government. In July 1992, the Law on permanent closeout of the mine passed and according to this a programme on its closeout is being prepared for the Ministry of the Environmental Protection and Physical Planning. The programme has been presented to the local communities and to the Government. All questionable points have been discussed and resolved in the presence of a local community representative and consequently, the programme was accepted by the Government in April 1994. This programme is the so-called plan document for all the closeout activities and for the project financing. The closeout of the Žirovski vrh Uranium Ore Mine is to be carried out in four technical and technological steps: closeout of the mine, processing plant, tailing and waste rock piles, and monitoring of the environmental impacts during and after closure.

1. INTRODUCTION

Production in the Žirovski vrh Uranium Ore Mine (RUŽV) began in 1985 with the capacity of 120 t of uranium concentrate U_3O_8 per year. The up-to-date uranium ore production capacity, by 1990, has covered 540 000 t and the uranium concentrate production 450 t.

The Žirovski vrh Uranium Ore Mine stopped its regular operation in 1990. This was influenced by economic reasons, since the yellow cake production has not been justified anymore. Other parallel viewpoints are the requirements for environmental protection which demand the closeout of the Nuclear Power Plant Krško and the cessation of all activities in connection with it.

The problem of the Žirovski vrh Uranium Ore Mine closeout is expressed in two main points:

- planning and performing of the mine permanent closeout, including a permanent environmental protection against all consequences,
- transformation of the existing objects and equipment in view of a successful substitutional activity and new personnel employment.

By the decision of the Government of the Republic of Slovenia in 1990, the Žirovski vrh Uranium Ore Mine had to close out temporarily. The study of alternative possibilities of further development of the Žirovski vrh Uranium Ore Mine, elaborated in January 1991, showed, that the operation of the mine is not justified and that an optimal solution would be to permanently close it out.

In July 1992, the Law on permanent closeout of the Žirovski vrh Uranium Ore Mine passed and according to this, the mine shall be closed out and the environment protected against all consequences of mine exploitation by due precautions.

The following measures shall be applied:

- planning and performing of temporary environmental protection, until the program of permanent closeout of the Žirovski vrh Uranium Ore Mine is to be accomplished;

- planning and performing of the objects closeout;
- planning and performing of the permanent environmental protection against all consequences of the uranium ore mine exploitation and the necessary decommission;
- monitoring assurance over environmental protection, including radiological and meteorological monitoring in time of closing out and after it;
- attendance of the medical situation of workers who work or have worked on the positions with a beneficial length of service.

2. PROGRAMME FOR THE CLOSEOUT OF THE ŽIROVSKI VRH URANIUM ORE MINE

The closeout of the RUŽV is to be carried out on the basis of four separate technical and technological parts:

2.1. Project for the closeout of the Žirovski vrh uranium ore mine with permanent environmental protection against the consequences of mine exploitation

The project takes into consideration the permanent protection of the soil against the settlements, the protection of the pit mine against the ingress of surface waters, airtight gate of the pit mine and free discharge of water from the mine.

The Žirovski vrh Uranium Ore Mine had in time of investigations, construction and operation the capacity of ca. 1 200 000 m^3 (estimated volume). The necessary construction time and means for the excavation of the pit mine reward a certain value to these capacities. Before abandoning them and making them inaccessible, it is necessary to specify the possibility of their utilization in other purposes and consequently to reduce the foreseen cost of the closing out. At the same time, new working places shall be assured to the population of the area.

Regarding the state-of-the-art of the objects and the technology development of the Žirovski vrh Uranium Ore Mine, the permanent closeout of the same could be carried out in different variants regarding the filling material and its quantities. Partly filling up of the mine and the rehabilitation of tailing impoundment and waste rock piles as well as the utilization of a part of the mine for other purposes and utilization of the major part of outer objects for substitutional economic activities will take place.

Workers number and qualification, as well as time of activities implementation and costs have been defined for each activity separately.

2.2. Project for the closeout of the uranium ore processing plant with permanent environmental protection against the consequences of uranium concentrate production

The project deals with permanent solution for the closeout of the processing plant with emptying the reservoirs and tanks that contain various substances or chemical liquids, eluation of organic phase and ammonia removal. Ammonia stripping is the next phase as well as the controlled outlet of treated waste and technological waters in the water flow. This is followed by a decontamination of buildings, equipment and dismantling.

The basic aim of the uranium concentrate production closeout is a decommissioning of plants, objects and environment in such an extent that, in the sense of radiology and safety, an unlimited utilization of objects after the works settled shall be possible. A cost justified decontamination and dismantling shall be accomplished. The basic purpose is to enable an unlimited further utilization of building structures and grounds.

Permanent closeout of the uranium concentrate production shall be carried out by the following technological and technical processes:

- uranium precipitation and storage,
- neutralization of waste water phases,
- disposal of solid waste on waste rock piles,
- decontamination of all the equipment and pipe installations of the uranium concentrate production and further dismantling and radiological control of decontamination,
- classification of the equipment after decontamination
- according to the remaining decontamination level,
- recovery of the organic phase and, after extraction, uranium storage,
- after ammonia elimination from the processing water, the controlled outlet of the latter in the water flow,
- removal of all equipment foundations and unnecessary structures from the buildings, this is followed by decontamination and cleaning,
- removal of contaminated grounds and recultivation up to the elevations required,
- permanent storage of waste products in a special storage of contaminated waste in the mine.

Approximate evaluation of building materials quantity resulting from demolishing of individual objects is 4 300 m^3. The complete quantity shall be deposited on waste rock piles.

Besides building materials, the quantity of processing equipment, impossible to decontaminate rationally, is evaluated as well.

The complete quantity of contaminated processing equipment is evaluated to 110 m^3. This waste shall be properly conditioned and deposited most likely in specially prepared pit chambers.

2.3. Project for the closeout of tailing and waste rock piles with permanent environmental protection against the storage and disposal effects

It treats permanent stabilization of tailing and waste rock piles including protection against accumulation of water in the tailing, corrosion, dissolving of soluble components into the ground water and surface waters and determines the covers for the protection against air contamination caused by the emission of radon.

The tailing pile has a surface of ca 4.3 ha, the quantity of the tailings being 666 000 t or 375 000 m^3. The tailings represent 593 000 t and the waste rocks 73 000 t, the latter being used for the solidification of transport roads on the tailing piles.

The tailing pile is an object, the revitalization of which demands extensive and quite demanding work. Three basic solutions are possible:

- Option a:
  Relocation of a tailing part (ca 130.000 m^3) into the mine chambers and suitable revitalization of the tailing piles.

- Option b:
  Removal of complete tailing from the location, in connection with the planned closeout of the mine and the waste rock piles (tailing relocation in the mine chambers) as well as rehabilitation of former tailing piles location.

- Option c:
  Relocation of complete tailing and its disposal to another residence, rehabilitation of the former tailing pile.

Removal of the tailing pile to a completely new location is not foreseen since alternative location which shall better meet the requirements in all respects is not known. In any case, measures for the stabilization of the tailing pile, being situated on an active land slip, shall be carried out. Owing to a long term revitalization period according to any variant, there is a quite actual danger of land sliding and consequently of the sliding of a greater part of the tailing pile.

During tailing pile revitalization the following measures shall be carried out:

- permanent tailing pile stabilization shall be assured. For this purpose, the implementation of a draining tunnel and a draining curtain is provided,

- the tailing pile shall be covered to reduce the exhalation of radon under permissible values,

- the cover shall be protected from erosion by a green pass and a system of surface water draining.

The waste rock pile is a disposal of waste rocks as well as of a part of uranium ore processing waste. The surface of the waste rock piles is ca 4.3 ha and the complete quantity of the disposed materials is 1 472 150 t, 1 420 350 t being the waste rocks, 48 000 t being the red mud and 3 800 t being the filtration waste of the treatment plant.

On the basis of analysis of the waste rocks contamination it was found out that they shall be treated in the same way as the tailings, that is why the guidelines for a permanent waste rock piles revitalization are the same as in case of the tailing piles.

2.4. Monitoring of the environmental impacts after the closeout of the production unit at Žirovski vrh uranium ore mine

It will assure the compliance with the valid regulations in the field of environmental protection and public health and provide for the measurements of all the emissions that are to be in conformity with the permissible values.

The scope of measurements and monitoring shall stay the same as during the production for at least 2 years after the permanent closeout. On the basis of the trends established, and according to the previsions, a reduced monitoring shall be carried out. For this purpose, a monitoring project of environmental impact assessment of the uranium ore exploitation shall be carried out. It shall:

- determine the methodology, location, terms and period of defining impacts of the permanent closeout of the Žirovski vrh Uranium Ore Mine,

- determine limiting values of the exploitation impacts, on the basis of which the rehabilitation shall be carried out,

- assure the necessary attendance of the workers health condition and determine the methodology, terms and periods of attendance as well as workers whose health condition shall be attended upon.

For the rehabilitation part of work, the environmental impact assessment, as it is declared by the law on environmental protection, is foreseen.

3. CONCLUSIONS

- The programme provides several variants of closing the mine which must be accomplished during the next phases of the elaboration of technical documentation.

- One of the urgent problems emerging at the moment is the sliding of the tailing pile which must be stabilized as soon as possible.

- In the programme, the closeout activities were determined and the estimation of costs and the time schedule were established.

- The cost of the mine closeout is estimated to ca. 60 millions ECU, i.e. for the total closure of the mine in a period of six years. Cumulative investments per year are shown in Figs 1 and 2.

- Owing to the high value of the mine, shown in Fig. 3, the transformation of the existing facilities in order to be used for substitutional activities must be taken into consideration.

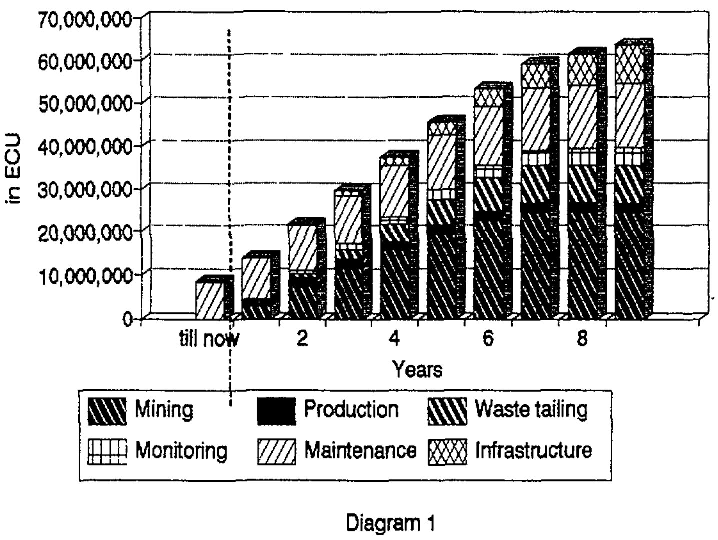

FIG. 1. Cumulative investment per year, option a.

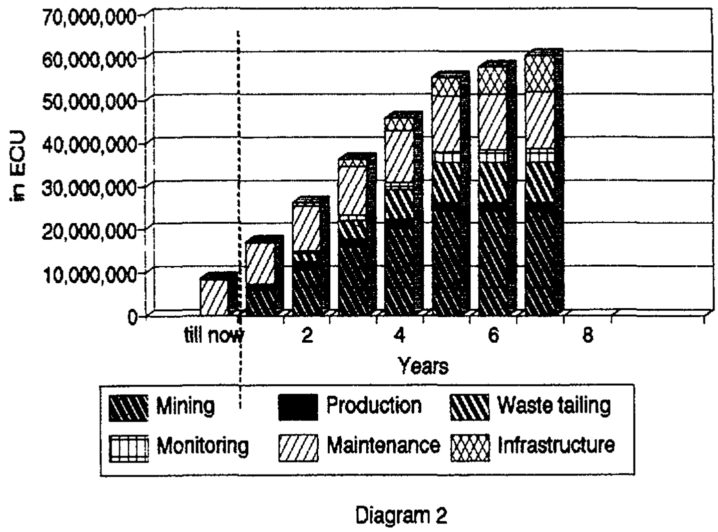

FIG. 2. Cumulative investment per year; option b.

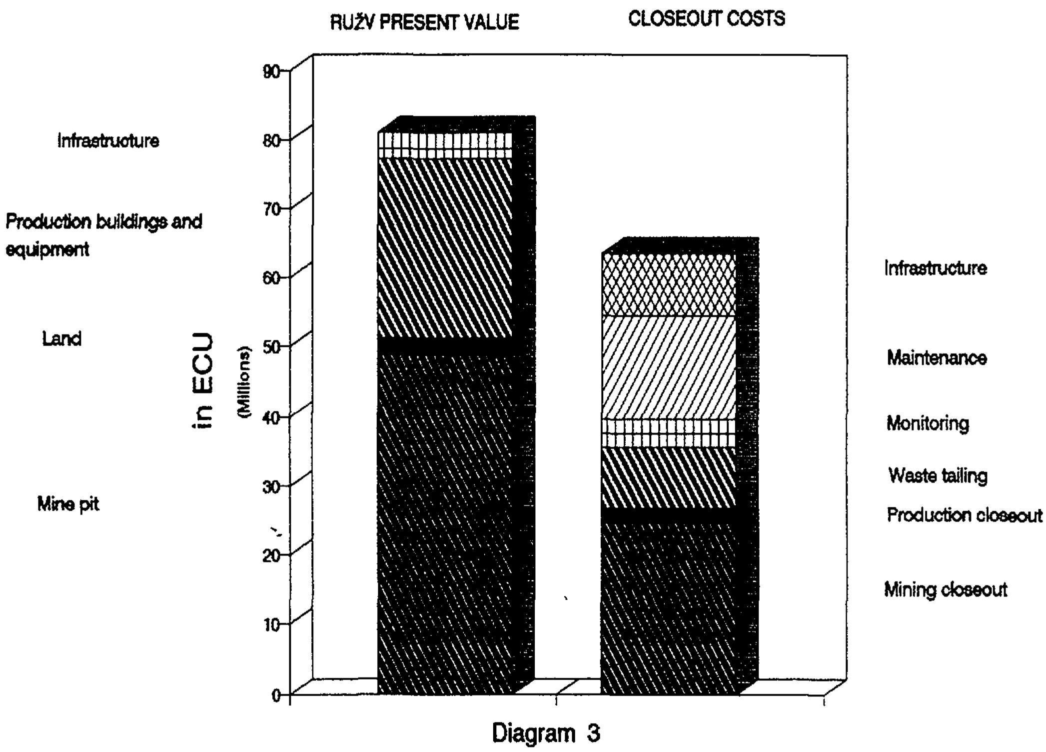

FIG. 3. Closeout costs compared to RUŽV present value.

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INVESTIGATION FOR CLOSEDOWN ACTIVITIES
IN THE URANIUM MINE ŽIROVSKI VRH

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Abstract

The uranium mine Žirovski vrh was temporarily shut down by order of Government of the Republic of Slovenia in the second half of the year 1990. After the Slovenian parliament passed the law on definite closing down of the uranium mine exploitation and on rehabilitation the effect of mining on the environment in July 1992 was starting to make the Programme of the Permanent Closing down of the Uranium ore Exploitation and Permanent Protection of the Environment in Uranium Mine that is in final phase. In the meantime the studies that would define necessary parameters for elaborating the projects of closure have been done. Two essential studies for the realization of closure of mine are working out: 1. Previous dewatering of the deposit by boreholes for diminishing of pollution of mine water by uranium; 2. Filling of partially collapsed stopes by hydrometallurgical waste to assure permanent stability above the mine spaces. The aim of the first study is to reduce percolation of mine water through the mineralized parts of the deposit by drilling boreholes in the footwall and in the hanging wall. Pollution of mine water which outflows from the lowest tunnel in the local creek Brebovščica should be diminished. Tests of stability and lixiviation on the cubes that are made of hydrometallurgical waste are the topic of the second study. Cement and different additives are added in the cubes and testings have been made in situ.

1. INTRODUCTION

At the end of the 1960s and in the 1970s extensive geological explorations were done in the deposit Žirovski vrh to assure later excavation. A mine water appeared by exploratory drilling and

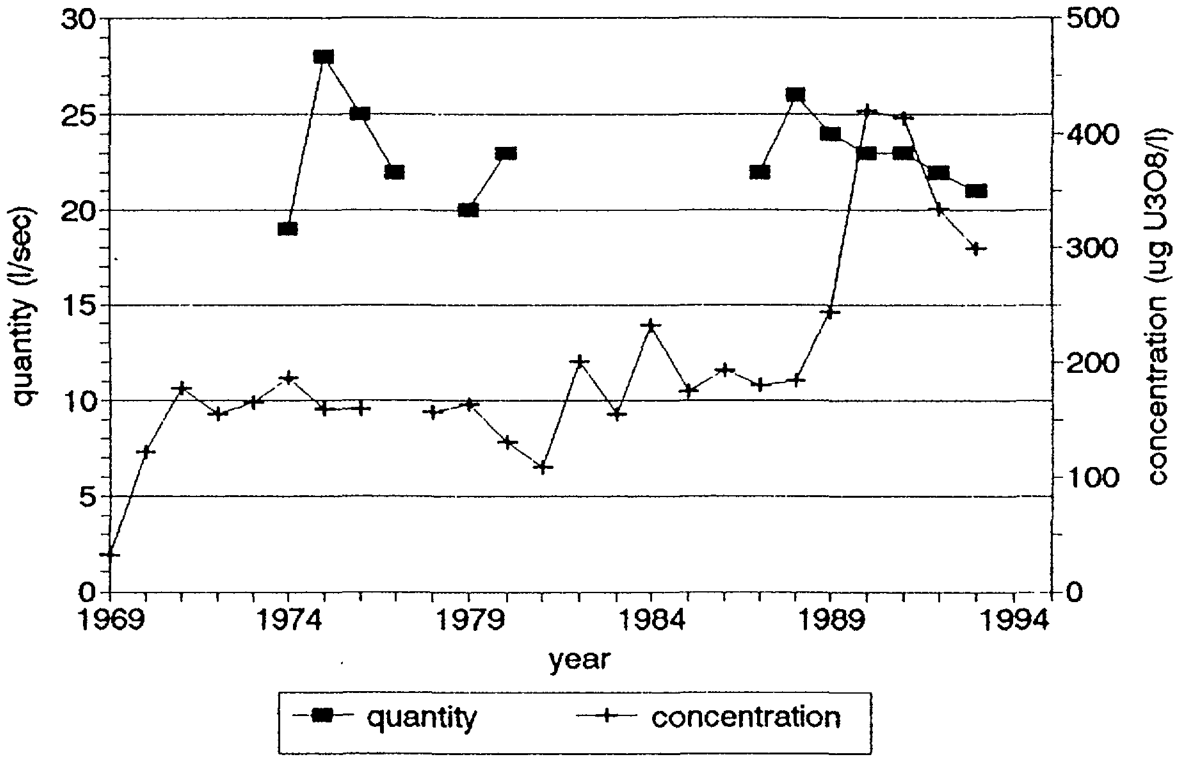

FIG. 1. Run of mine water by years.

in the headings. It drained toward the lower entry and after it outflew into the brook Brebovščica. Its quantity was changing in the dependence on rainfall, quantity and intensity of mining. The greatest outflow of minewater appeared in the years before closedown due to attribution of technological water. After the closedown the outflow settled. It has been changing in the dependence on rainfall only (Fig. 1).

Uranium ore was winning by two mining methods:

- at the beginning by room and pillar method
- for last 3 years back filling mining method prevailed

Many empty stopes remained about all as a consequence of ore winning by first mining method. In the meantime a part of them collapsed. After closedown stability analyse of a space above stopes was made. It was ascertained that we should fill up the empty stopes for assurance of long term stability above the mine. Backfill with addition of cement should reach a strength of about 2 MPa.

2. PREVIOUS DEWATERING OF THE DEPOSIT BY BOREHOLES FOR DIMINISHING OF POLLUTION OF MINE WATER BY URANIUM

2.1. Geological features

The uranium mineralization has formed in grey coloured Groden sandstones and conglomerates which are intercalated by green and red ones. The ore bearing zone rests unconformably upon a Carboniferous shale in the footwall while in the upper part thick beds of red shale covers it. The deposit is dissected by a few minor faults with a NNW-SSE trend. The faults have small throws usually under 10 m and we can follow them to some hundred meters in length. The Young Paleozoic complex is thrust on Upper Triassic dolomite (Fig.2).

2.2. Hydrogeological characteristics

Fractured porosity developed in the Groden rocks. The beds are usually slightly permeable except in the fault zones where the permeability is increased. Carboniferous shale in the footwall is impermeable, while the red mudstones above the mineralized part is slightly permeable to impermeable. The quantity of mine water which drains through the deposit is relatively small. However by the water seepage over the mineralized surfaces uranium has been lixiviated. A review of changing of uranium content in the outflow of mine water is shown in Fig. 1. Increased uranium pollution after 1987 coincides by intensive excavation of uranium ore and consequently the decrease is due to closedown in the year 1990. The worth has stabilised now at level 300 ppb $U_3O_8/1$.

In the period of mining, the mud in mine water was the greatest pollutant. By startup of treatment plant this problem was overcome. But dissolved uranium in the mine water would remain a problem for a long time because it will outflow to local stream.

2.3. Diminishing of pollution

On a model of seepage of mine water we concluded that its pollution could be diminished. Uranium has been dissolved by seepage of mine water through the central mineralized part of the deposit. Inflows outside of the mineralized zone are still pure. Pollution of mine water by capturing these pure waters before their seepage trough mineralized parts should be decreased. First borehole which was drilled on the lower level of the mine confirmed our idea. As we can see in Fig. 3, the

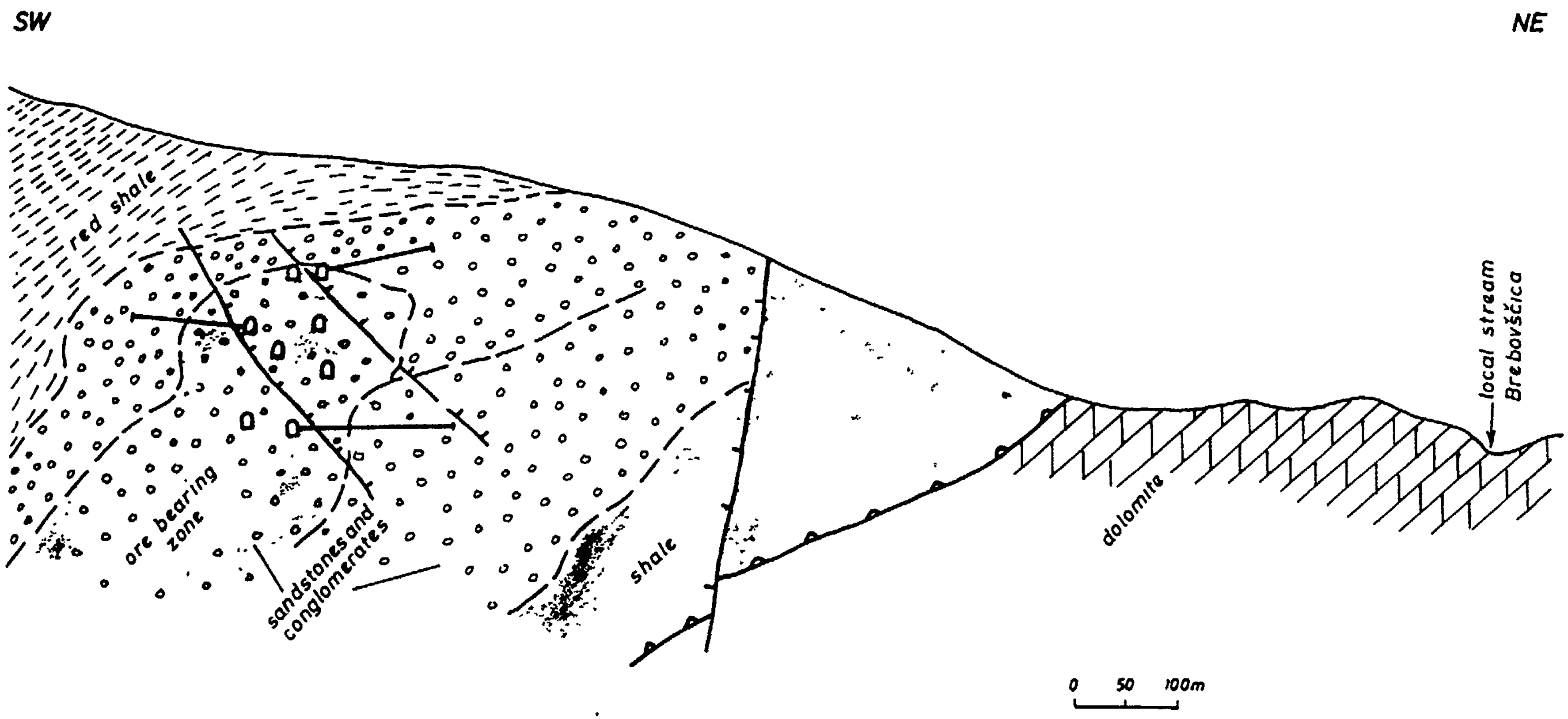

FIG. 2. Cross-section of the mine area with designed boreholes.

TABLE I. MILL TAILING COMPOSITION

Chemical composition[1]				
ELEMENT	SYMBOL	UNIT	VALUE	TEST SAMPLE
Aluminium	Al	%	5.5	
Calcium	Ca	%	3.6	2.1
Calium	K	%	0.6	
Magnesium	Mg	%	0.41	0.64
Sodium	Na	%	1.2	
Iron	Fe	%	1.2	
Quartz	SiO_2	%	62.50	
Sulfate	SO_4	%	5.7	4.9
Arsenic	As	ppm	153	
Cadmium	Cd	ppm	19	
Cobalt	Co	ppm	30	106
Copper	Cu	ppm	98	
Chromium	Cr	ppm	22	721
Lead	Pb	ppm	970	133
Manganese	Mn	ppm	842	
Molybdenum	Mo	ppm	<10	
Nickel	Ni	ppm	11	
Phosphate	P_2O_5	ppm	130	
Strontium	Sr	ppm	87	
Thorium	Th	ppm	24	58
Uranium	U_3O_8	ppm	120	301
Zinc	Zn	ppm	164	
Vanadium	V	ppm	110	
Radiological composition[2]				
Radium	Ra-226	Bq/kg	8700	
Uranium	U-238	Bq/kg	1000	
Thorium	TH-230	Bq/kg	3600	
Lead	Pb-210	Bq/kg	<8600	
Polonium	Po-210	Bq/kg	<8600	

[1] Weekly composite 12.04.1990

[2] From Final Report, ... IJS July 1992, Uranium (Raw Materials, Production 1992, Comparison of provisions and procedures ... IJS 1992 (all in Slovene)

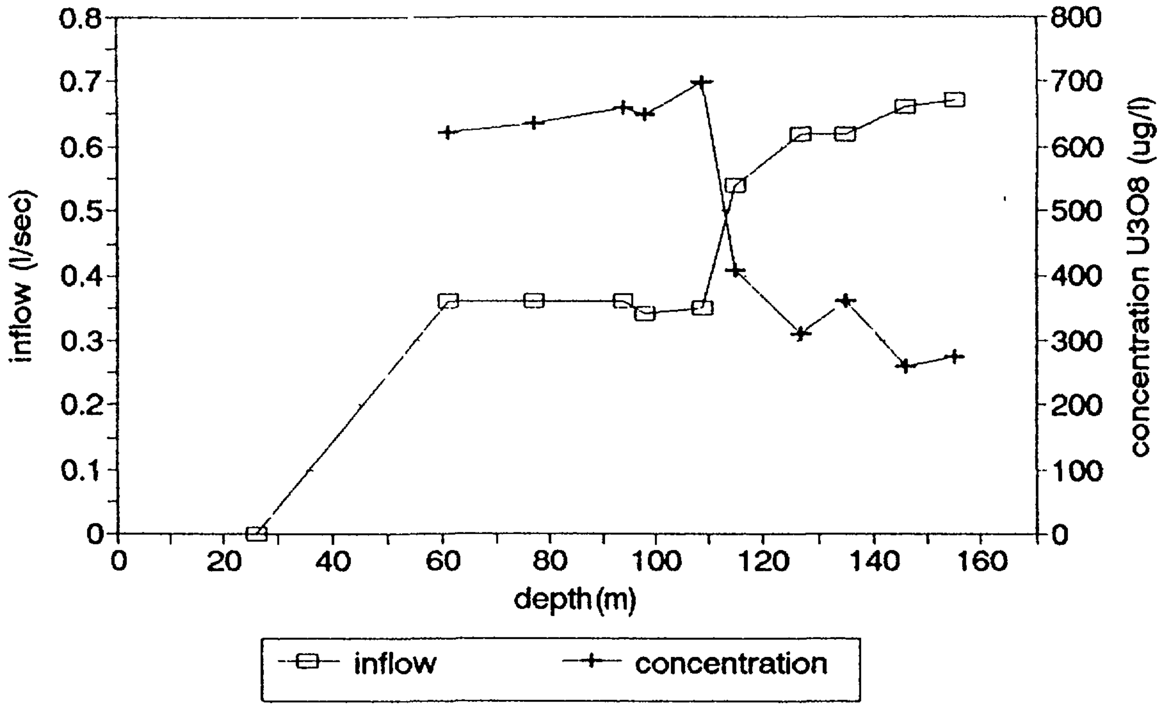

FIG. 3. Inflow and pollution of water from borehole.

first inflow in the borehole had still increased uranium content but later we drilled on pure waters and consequently pollution dropped. We design to bring down the pollution of mine water by borehole for 20-30%.

3. FILLING OF PARTIALLY COLLAPSED STOPES BY HIDROMETALLURGICAL WASTE TO ASSURE PERMANENT STABILITY ABOVE THE MINE SPACES

2.1. Properties of hidrometallurgical waste

Hidrometallurgical waste is fine grained material with grain diameter under 0.6 mm and moisture about 15-20%. On the tailing disposal it is mixed by remains of crushed rods, tapes for dewatering of pore water and coarse grained mine waste. From the total quantity of 666 000 tonnes the hidrometallurgical waste involves 593 000 tonnes and mine waste 73 000 tonnes. Chemical and radiological composition is shown in the Table I. Owing to washing of the hidrometallurgical waste in the pore water and moisture the soluble salts appear. Ammonium, calcium and magnesium sulphate are well soluble as is evident from chemical investigation of 10% eluates from hidrometallurgical waste which is shown in Table II (the first eluate).

2.2. Investigation of the hidrometallurgical waste

The purpose of physic-mechanical and chemical investigation of the hidrometallurgical waste is to provide receipt and additions for optimal concrete mixture and to determine comprehensive strength and degree of lixiviation of chemical and radiological pollutants. Mixtures of crushed mine waste with hidrometallurgical waste have also been investigated. For this case a great deal of improvement of physic-mechanical properties for these concrete mixtures are expected.

TABLE II. CHEMICAL COMPOSITION OF ELUATES

Element	Unit	from crude tailing
pH		5.6
Conductivity	mS/cm	2.16
U_3O_8	μg/l	16
Ammonia	mg/l	1.1
Sulphate	mg/l	1496
Calcium	mg/l	522
Magnesium	mg/l	2.5
Copper	mg/l	0.11
Manganese	mg/l	0.78
Lead	mg/l	<0.5
Zinc	mg/l	0.09

Sample mark HM15BD01

In the second part we need to provide optimal mixture for pumping possibility and to determine equipment for realization of pumping of the hidrometallurgical waste into the open stopes.

2.3. Preliminary tests or stability of the cubes

Test concrete cubes of different quality and with different additions for diminishing its porosity were made. In this first phase we are testing the impact of quantity of cement and additions on its stability under various atmospheric conditions on the surface and underground (temperature, moisture, precipitations). Similar test has also been considered for the mixture of mine and hidrometallurgical waste.

2.4. Eluates from the cubes

High conductivity and pH and presence of well soluble salts were indicated from the first analyses of 10% eluates from the cubes.

3. CONCLUSION

Hidrometallurgical waste resulted as a relatively bad material as a filling concrete. But it could be applicable in dependence on requirement. A low comprehensive strength at relatively great consumption of cement was reached. Mixing with mine waste has resulted favourably of course. We should take into account that the waste has been already there and that its use in the mine would successfully resulted in the prevention of waste disposal sliding.

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THE DEVELOPMENT OF A TAILINGS DECOMMISSIONING CONCEPT: A CASE HISTORY, RABBIT LAKE, CANADA

(Abstract)

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The Rabbit Lake mine and mill facility is located in northern Saskatchewan, Canada, at the northeastern edge of the Athabasca Basin. The Rabbit Lake orebody was discovered in 1968. From 1975 to 1985, approximately 6.5 million tonnes of tailings were deposited in a valley confined by bedrock ridges and two earth-filled dams. Planning for the decommissioning of the Rabbit Lake tailings management facility started in 1983 when the relocation of the tailings into the mined out Rabbit Lake open pit and alternatively, the in-situ decommissioning were examined. The latter was preferred since it offered a sufficiently low individual dose rate and an insignificant environmental impact. Subsequent to the regulatory approval in 1984 to pursue the in-situ decommissioning, three options were considered: (1) A concave surface with natural cover, surface water management and dam stabilization, (2) a convex surface with natural cover, surface water management and dam stabilization and (3) a minimum reclamation option incorporating surface water management only. The 1986 study concluded that the collective public dose over the 1000-year modelling period was acceptable for all three options. However, the concave option was recommended for the final surface shape because it appeared to offer structural integrity and cost effectiveness. The regulatory agencies responded favourably but requested in 1986 that a final surface configuration be adopted only after initiation of tailings dewatering measures and additional field studies. By 1988, an electromagnetic conductivity survey, a pathway analysis, a stream flow reconnaissance and continued environmental monitoring in the vicinity of the tailings area were completed. Subsequent recommendations included the hydrogeological modelling of the area, the hydrogeological evaluation of a cover, the installation of additional piezometers, further geotechnical drilling of the tailings, a radiometric survey, surficial sampling, thermal and consolidation modelling, update of the pathway analysis and a rerun of the electromagnetic survey. These activities were completed by 1991. On the basis of the results, the cover design was optimized taking into account areas of higher consolidation defined by the presence of distal slimes and frozen layers. In addition, pre-loading of the slime area was considered to alleviate post-construction settlements.

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DECOMMMISSIONING OF URANIUM MILL FACILITIES

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Abstract

The milling of radioactive ores results in contaminated buildings and facilities which must be decommissioned, and large quantities of tailings which must be managed safely so that residual environmental and health risks do not exceed acceptable levels. In the south of Spain on the outskirts of the town of Andújar an inactive uranium mill facility is under decommissioning. Mill equipment, buildings and process facilities have been dismantled and demolished and the resulting metal wastes and debris have been placed in the pile. The tailing mass is being reshaped by flattening the sideslopes and a cover system will be placed over the pile. This paper describes the safety aspects and technical approaches which are being used for the remediation and closure of the Andújar mill site.

1. INTRODUCTION

Empresa Nacional de Residuos Radiactivos, SA (ENRESA) is remediating an inactive uranium mill facility in the town of Andújar in the south of Spain. The Andújar plant became operational in 1959 and continued in operation until 1981. All solid waste generated during the operation of the plant are contained in a tailings pile, which covers an area of 9.4 hectares and has a total volume of about one million cubic metres. The pile was constructed in five cells by upstream construction to a height of 20 m in the central and eastern parts and to a height of 10 m in the western part. This paper summarizes the criteria used for the remediation and closure of the Andújar mill site and discusses the safety aspects associated with the decommissioning of the mill facilities.

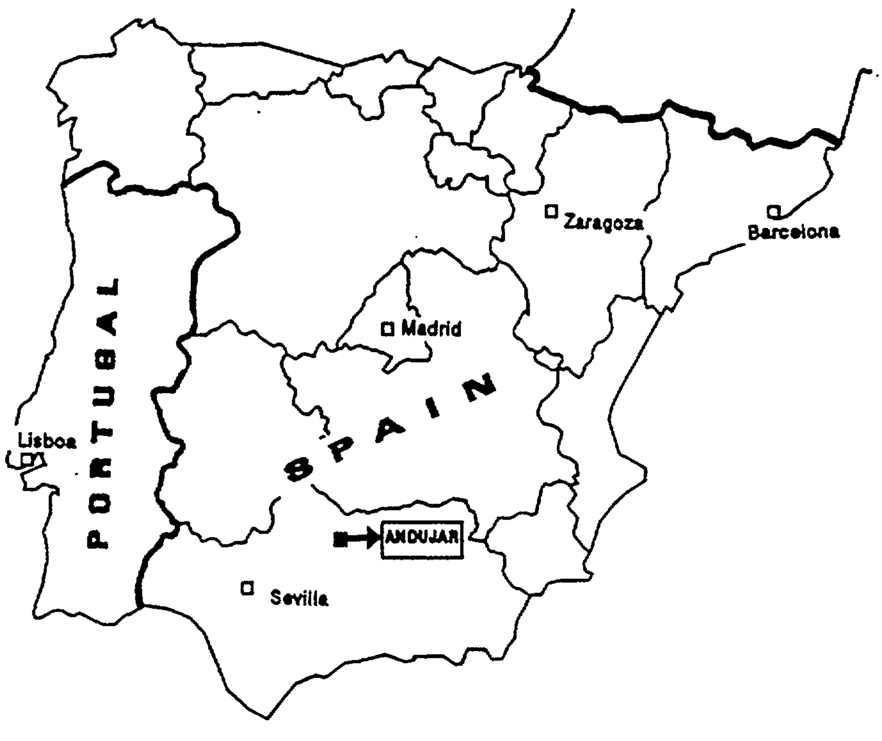

FIG. 1. Site location.

2. MILL FACILITY CHARACTERISTICS

The Andújar Uranium Milling Plant is in the province of Jaén (Andalucía) on the southern floodplain of the Guadalquivir river at 1.5 km south from the urban center of Andújar . The location of the site is given in Fig. 1. The site is trapezoidal in shape, covers and area of approximately 17.5 hectares and is contained within a peripheral wall, which is about 150 m from the course of the river.

The plant was designed for processing low grade uranium ore (0.15% of U_3O_8) and produced 80% concentrate of U_3O_8,, in the form of sodium and ammonium uranate at a rate of 60 to 80 tonnes per year. The plant became operational in 1959 and continued in operation until 1981. During this period 1.2 million tonnes of uranium ore were processed to produce 1 350 tonnes of U_3O_8 with a fineness of 80-85%. Recovery of the uranium involved sulphuric acid leaching followed by ion exchange or by tertiary amine/Kerosene extraction. Solid wastes were stored in the tailings piles and liquid wastes were treated before disposal to the Guadalquivir river.

The configuration of the Andújar mill site is shown in Fig. 2 and includes the following areas: the tailings pile, the processing plant, the waste water treatment area, the auxiliary and administrative buildings and the housing area.

All solid waste generated during the plant's operation (1.2 million tonnes) are contained in the tailings pile, which sideslopes vary from 25 to 35 degrees and has a total activity of 4 500 Ci.

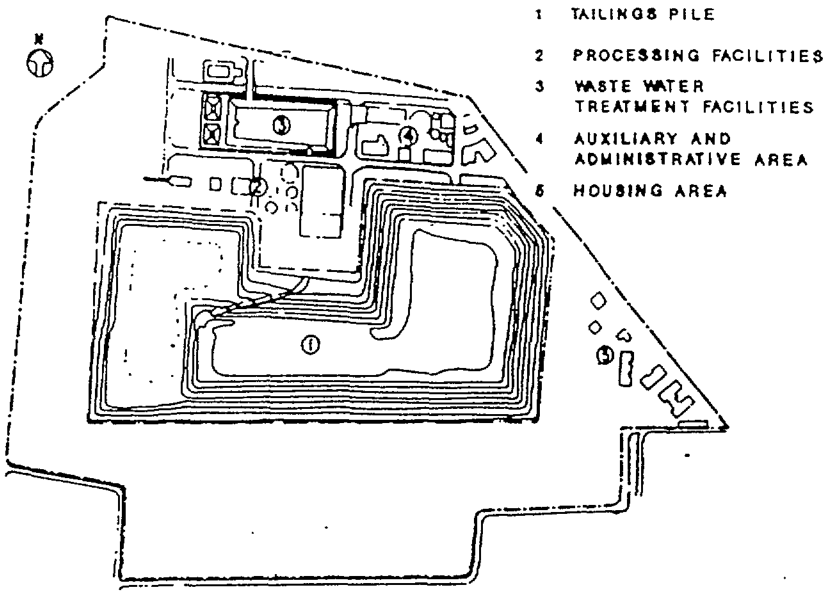

FIG. 2. Present configuration of Andújar mill site.

3. SAFETY ASSESSMENT

Safety analyses were carried out to determine the short term and long term consequences (risks) to humans and the environment associated with the inactive milling site and the proposed decommissioning actions. Risks may arise from the tailings pile, the mill facilities and buildings and the contaminated soils around the site and may be generated by events such as:

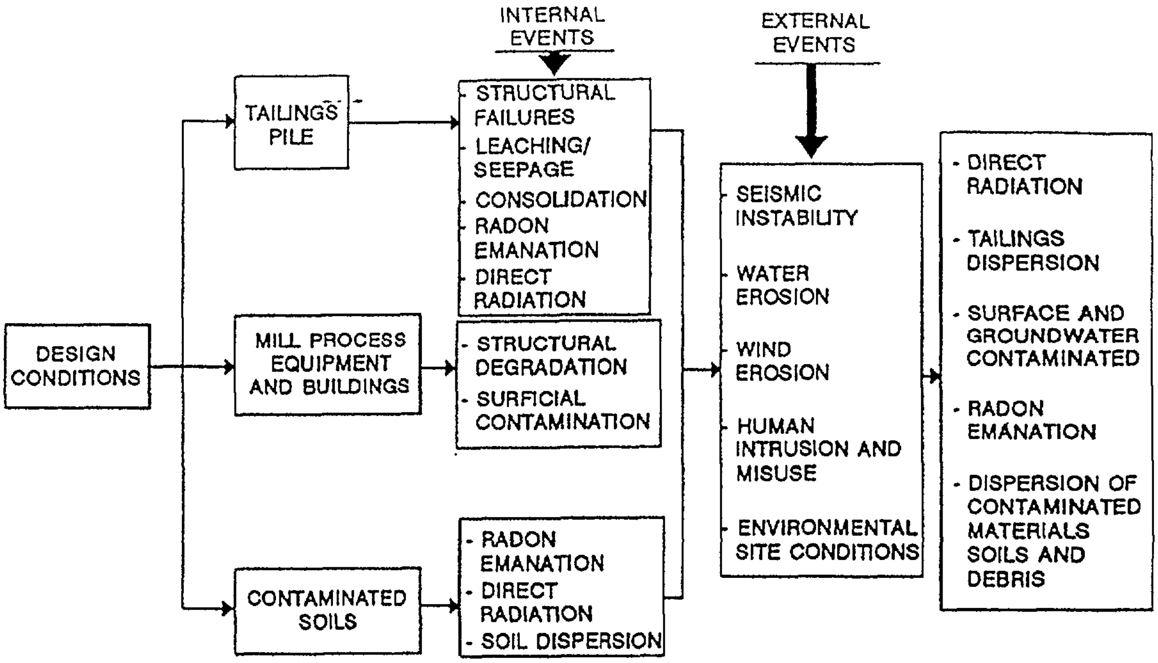

FIG. 3. Potential risks associated with inactive mill facilities.

- Humans actions associated with intrusion into tailings or removal of contaminated materials,

- Dispersion of contamination via air/water pathways,

- Massive migration of tailings/contaminated materials as a result of structural failure or degradation of the pile and/or the buildings.

Scenario analyses were performed in which release and transport scenarios for radioactive pollutants were defined, followed by consequence analyses in which the radiological effects of the releases to the environment were evaluated.

The various scenarios considered for the Andújar mill site are shown in Fig. 3. Important release mechanisms include: radon emanation, seepage and uncontrolled release of contaminated water, structural or seismic instability, wind and water erosion or dispersion, unauthorized removal of tailings and/or contaminated soils or materials.

Major risks associated with the decommissioning of mill facilities are listed below:

- Direct gamma radiation produced by radioactive decay series of the U-238,

- Tailings dispersion due to wind or water erosion and human or animal intrusion,

- Contamination of surface waters due to water erosion and surface runoff which result in the dispersion of radioactive particles in the waters,

- Groundwater contamination as a result of seepage of rainfall water through the tailings and the substratum and contaminant migration to underlying aquifers,

- Radon emanation produced in the radioactive decay sequence of Ra-226,

- Dispersion of contaminated materials and/or soils by wind, water erosion, human or animal intrusion.

Major pathways by which the released pollutants can reach the environment and humans are as follows:

- Atmospheric pathways which lead to irradiation by inhalation of radon and its daughters, inhalation of airborne radioactive particles and external irradiation,

- Atmospheric and terrestrial pathways which can cause doses due to ingestion of contaminated foodstuff and external irradiation,

- Aquatic pathways which can result in the ingestion of contaminated water, foods produced using irrigation, fish and other aquatic biota, and through external irradiation,

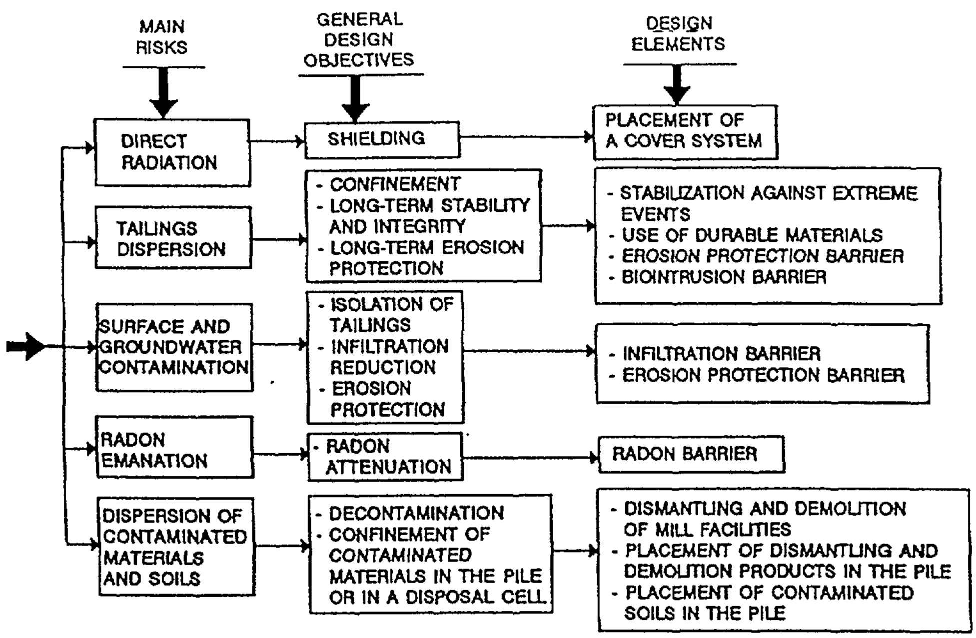

FIG. 4. Objectives and design elements.

To ensure that risks were adequately controlled, a set of fundamental safety and design criteria were established, as shown in Fig. 4. Primary objectives were the following:

- Dispersion and stabilization control, to ensure confinement and long term stability of tailings and contaminated materials,

- Erosion control to prevent surface water contamination and ensure long term integrity of the closed out facility,

- Radon control to reduce radon emissions,

- Groundwater protection to prevent groundwater contamination by rainfall waters infiltrating into the tailings.

To achieve these objectives, the following design elements were incorporated into the decommissioning plan (Fig. 4).

- Stabilization against extreme events by slope flattening and pile reshaping,

- Dismantling and demolition of mill facilities and buildings, and placement of metal wastes/debris in the pile,
- Placement of a cover system including a radon barrier, an infiltration barrier, a biointrusion barrier and an erosion protection barrier.

4. REGULATORY AND DESIGN OBJECTIVES

The regulations and standards that govern the remediation activities at Andújar have been established by the Spanish Nuclear Safety Council (CSN), taking into account the recommendations of international organizations (ICRP, IAEA and OECD/NEA), the standards promulgated by the U.S. Environmental Protection Agency for the remediation of uranium mill tailings and the Spanish regulations, specifically those related to groundwater protection and the long term disposal of radioactive wastes. These regulations may be summarized as follows:

- Dispersion Control: Prevent inadvertent human intrusion and dispersion of contaminated materials by wind and water erosion.
- Long-term Radiation Protection: Achieve an effective equivalent dose to the individual in the critical group below 0.1 mSv/year.
- Design Life: Remain stable for 1000 years to the extent reasonably achievable and in any case for at least 200 years.
- Soil Cleanup: Reduce the residual concentration of radium-226 in land, averaged over an area of 100 m^2, so that the background level is not exceeded by more than 5 pCi/g (averaged over the first 15 cm soil) and is less than 15 pCi/g (averaged over 15 cm thick layers of soil more than 15 cm below the surface).
- Radon Control: Reduce radon flux over the surface of the final pile to an average release rate of less than 20 pCi/m^2.
- Groundwater Quality Protection: Control groundwater contamination so that background water quality or maximum concentration levels (in accordance with Spanish regulations and CSN guidelines for radioactive constituents) are achieved in the long term. These maximum levels are: combined radium-226 and radium-228 0,.8 Bq/l (4.86 pCi/l), combined uranium-234 and uranium-238 1.2 Bq/l (32.4 pCi/l) and gross alpha activity, excluding radon and uranium 0.5 Bq/l (13.5 pCi/l).
- Long term Maintenance: Minimize the need for long term maintenance.
- Construction Works: Minimize hazards to the workers and the environment.
- Regulations: Comply with other applicable and relevant Spanish regulations governing air and water quality in non radiological aspects.

With regard to groundwater quality protection, it is also required that for short term conditions the cover system be designed to limit infiltration to ensure that, at the end of the compliance period (minimum 10 years), the combined uranium-234 and uranium-238 concentration in groundwater complies with the two following conditions:

- Be less than 6.15 Bq/l (166 pCI/t) at the point of compliance, at the downgradient boundary of the disposal site.
- Be less than 3.5 Bq/l (94.5 pCI/I) at the wells in the vicinity of the site.

In addition to the above design standards, a performance standard has been established for Andújar : groundwater quality must be monitored during the compliance period (minimum 10 years) to confirm adequate performance of the cover and compliance with the maximum concentration limits established for short term conditions.

5. REMEDIAL ACTION PLAN

The remedial action plan proposed for Andújar mill site, involved stabilizing and consolidating the uranium mill tailings and contaminated materials in place. The actual tailings pile were reshaped by flattening the sideslopes to improve stability. Tailings from sideslope flattening were relocated around the existing pile and on the top of the lower pile. Mill equipment, buildings and process facilities were dismantled and demolished and placed in the tailings pile. Off-pile contaminated soils were excavated and placed on top of tailings pile in order to reduce the radon flux.

The final pile configuration, as shown in Fig. 5, was designed to minimize the movement of tailings and the size of the restricted disposal area. The pile was constructed with four percent topslopes and 20 percent sideslopes which provide static and dynamic slope stability without requiring excessively large rock to resist erosion. Protection against upland watershed runoff is provided by channelling runoff around and away from the pile via drainage diversions water along the perimeter of the pile. Protection against floods associated with the Guadalquivir river is provided by a rock apron around the perimeter of the pile and riprap layers on the sideslopes.

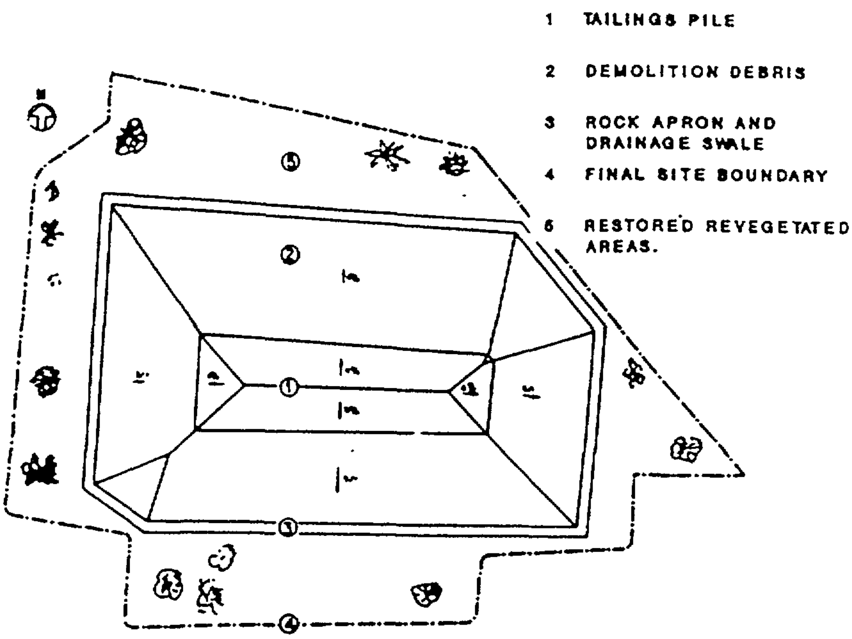

FIG. 5. Andújar site after remediation.

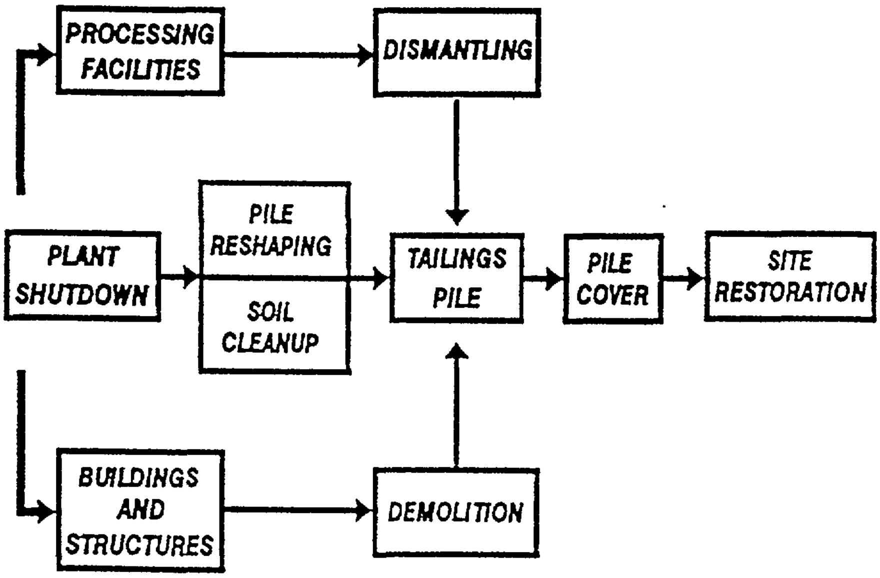

FIG. 6. Remedial action plan.

Decommissioning of mill facilities and buildings involved the dismantling of the facilities, the demolition of the buildings, the reduction of metal wastes and demolition debris to manageable pieces, the cementation of the metal wastes and the disposal of dismantling and demolition wastes in the tailings pile. Special containers were used to facilitate handling, transportation and cementation of the metal wastes. Cementation proved to be a cost-effective operation and provided a more stable structure to the wastes than the conventional alternative of mixing and compacting with the tailings.

The pile will be covered with a multilayer system to meet the three simultaneous demands of erosion control, infiltration and radon control. In order to comply with the standards, the following design elements are incorporated into the cover system:

- Stabilization control for up to 1000 years: Only natural materials are used and the cover is designed to resist extreme events such as probable maximum precipitation, probable maximum flood, maximum credible earthquake.
- Dispersion and intrusion control: erosion protection layers and biointrusion barriers within the cover.
- Soil clean-up: Remove contaminated soils and incorporate them within the tailings underneath the cover system. This reduces the thickness of the radon barrier.
- Radon control: a radon barrier of natural soils.
- Protection of groundwater quality a multiple redundant cover system to limit infiltration. This system includes soil/vegetation layers, drain layers and a low permeability infiltration barrier.
- Long term maintenance: a rooting medium for the establishment of climax vegetation. Major activities involved in the remedial action (Fig. 6) are listed below:
  - Preparation of the site including construction of a new waste-water retention basin to protect against release of contaminants, a decontamination pad to wash down equipment, field offices, and shower/change facilities.

- Construction of drainage control measures to direct generated waste-water and contaminated storm-water runoff to the retention basin during construction activities.

- Dismantling of processing facilities and burial of contaminated materials in the tailings pile.

- Demolition of mill buildings and structures and burial of debris in the tailings pile.

- Reshaping the existing tailings pile and excavating, transporting and placing off-pile contaminated materials on the tailings pile.

- Construction of the final cover system over the tailings to inhibit water infiltration. radon emanation, and wind and water erosion.

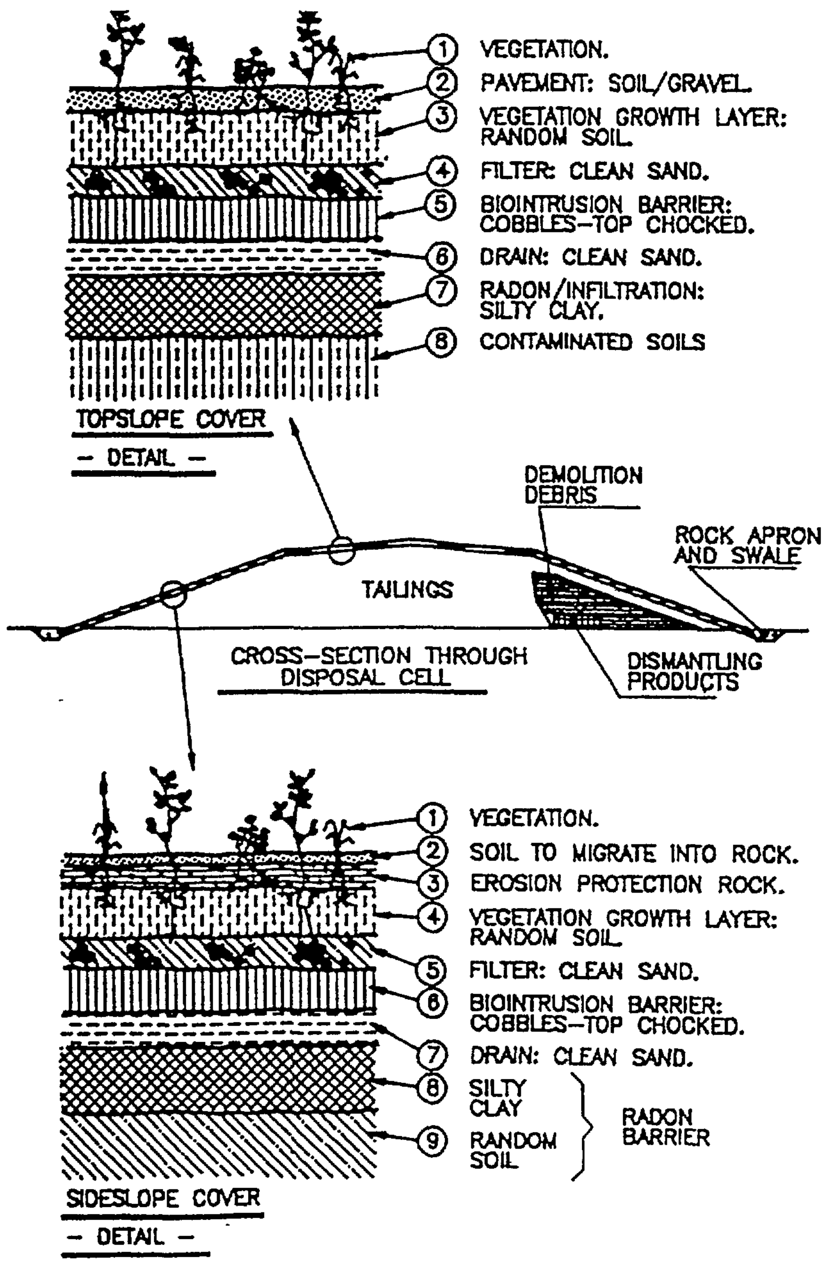

FIG. 7. Cover design for Andújar tailings pile.

- Restoration of the excavated areas, to ensure proper drainage.

- Revegetation of the pile and excavated areas on and adjacent to the processing site.

- Construction of the final fencing.

Fig. 7 shows the cover components for top and sideslopes of the final disposal cell The topslope consists of, from top down:

- 50 mm erosion barrier of mixed gravel and soil,

- 500 mm vegetation growth and desiccation protection zone of random soil,

- 250 mm filter of clean sand,

- 300 mm biointrusion barrier of coarse rock,

- 250 mm drain of clean sand,

- 600 mm radon and infiltration barrier of silty clay,

The most significant benefits of this cover are its ability to deal effectively with vegetation and to reduce infiltration to the cell because of effective evapo-transpiration. From the top down, the sideslope cover consists of:

- 30 mm of soil to migrate into the rock and help support vegetation,

- 300 mm erosion barrier of soil/rock matrix,

- 500 mm vegetation growth and desiccation protection zone of random soil,

- 250 mm filter of clean sand,

- 300 mm biointrusion barrier of large rocks,

- 250 mm drain of clean sand,

- 600 mm radon and infiltration barrier of silty clay.

Advantages of this cover include protection of the radon infiltration barrier from desiccation and the existence of a controlled zone — the random soil — for vegetation that might establish through the riprap and help reduce the visual impact of the remediated pile.

6. CONCLUSIONS

This paper has reviewed the design criteria and safety approaches followed for the remediation of the Andújar mill site. The decommissioning consists of stabilizing and consolidating the uranium mill tailings and contaminated materials in place. A multilayer cover will be placed over the pile to control water infiltration, erosion and radon exhalation.

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INSTITUTIONAL AND SOCIAL PARTICIPATION BY THE CITY OF ANDUJAR IN THE DECOMMISSIONING AND DISMANTLING OF THE ANDUJAR URANIUM MILL

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Abstract

The present paper describes a socioeconomic problem faced by the city of Andújar. This urban centre is located in the province of Jaén in southern Spain with a population of about 40 000. The Andújar uranium mill (AUM) which started in 1959 was the source of employment for the city's population. Through the twenty years of operation, there was no problem of social acceptance. After closure of the facility in 1981, there was a growing awareness among the public on matters related to radiological protection, management of mill tailings and environmental protection. The plan to decommission and rehabilitate the closed mill, which started in 1991, was the source of political debates and sensational journalistic reports that alarmed the population. A commission of the public was eventually formed to study, analyse and discuss its opinions with the government agency (ENRESA) which is charged with the decommissioning programme. These initiatives have allowed the public to develop a better understanding of the project. It is to be emphasized, therefore, that such an activity (decommissioning and rehabilitation) should go hand in hand with informative and socioeconomic measures explaining exactly the environmental situation of the sites.

The environmental recovery of sites previously occupied by uranium mines and mills is necessary in order to find a solution to the problems associated with such activities, problems which include economic, technical and scientific aspects. Having said this, it is rare indeed to encounter references to important problems of another nature which are involved in the performance of projects of this kind: socioeconomic problems.

It should not be forgotten that when we speak of experiences, methodologies and closures, we are faced with a reality which has both a physical and a human component: the city and its inhabitants.

From the very beginning of the project in the 1960s until its closure, the Andújar Uranium Mill (AUM) was considered in Andújar, a city of almost 40 000 inhabitants and located in the western part of the province of Jaén, close to the limits with the province of Córdoba, in the Autonomous Community of Andalucía, to be a provider of jobs. Throughout the twenty years during which the facility was in operation there were no problems of social acceptance.

By 1981, when the installation finally ceased to operate, new radiological protection and mine tailings treatment criteria had been developed. In addition, a new concept of environmental protection had found its way into public opinion.

Within the framework of this new sensitivity, the citizens of Andújar themselves have, in an orderly and paticipative manner, requested and promoted actions aimed at restoring the site, going beyond the objectives sought by simple research activities or by requests from environmentalists.

When in 1991 the first decommissioning and dismantling tasks had begun at the AUM, certain environmentalists associations and political parties attempted to use the closure and dismantling project to their own ends. Certain sensationalist views aired in the press centered on this issue, generating a sensation of some alarm among the population.

In short, two different perceptions of the matter may be identified:

- The fist, adopted by the largest part of the population of Andújar and most of the political and social groups in the city, consisted in viewing the problem in its true dimension and of channelling efforts towards achieving the best possible solution, this implying active co-operation with the Empresa Nacional de Residuos Radiactivos, S.A. (ENRESA).

- The second, adopted by a minority ignorant of the reality and history of the AUM, consisted of magnifying the problem and of comparing the risks involved with those popularly associated with nuclear power plants, thus taking advantage of the special sensitivity existing in Spain in relation to such facilities. The actions taken by those adopting this second standpoint served to create a distorted view of the reality of the issue, at times through press items, questions to Parliament... and on other occasions by promoting wrong impressions and doubt among the members of the public with regard to questions such as general health or pollution of water supplies.

It was realized that, in order to correct this situation, which was not a suitable platform from which to undertake the scheduled task of environmental recovery, it would be necessary to provide objective information on the works and to involve in the decommissioning and dismantling project all those who wished to participate, occupied posts of responsibility in the life of the city and enjoyed a level of credibility among the population. To this end a Public Tracking Commission was set up as a channel for direct communications between ENRESA and the people of Andújar. The Commission encompassed political parties, business associations, unions, neighbourhood associations and institutions having responsibilities for environmental issues. The University of Córdoba acted as an independent consultant to the Commission.

The Commission analyses the reports issued by ENRESA on the progress of the work and the radiological situation of the facility, and at the same time has powers to submit whatever initiatives it considers adequate in order to ensure better understanding among the members of the public of the tasks performed by ENRESA at the AUM. The following are some of the contributions made:

- Organization of a programme of visits to the AUM works.

- Visits to certain of the UMTRA project installations, in the United States, which are similar in characteristics to the AUM.

- Development of radiological protection courses for those members of the Tracking Commission who wish to widen their knowledge in this area and thus be in a position to analyse in greater depth the information supplied.

- Periodic reporting to the media regarding the progress and evaluation of the works.

- Organization of informative seminars aimed at different population groups.

These initiatives have allowed the public to develop a better understanding of the project than would have been possible if ENRESA had not actively collaborated.

Nevertheless there are still messages emanating from outside Andújar which, although no longer alarming its inhabitants, do harm to the image of the city and make its future projection more difficult.

Andújar has for many years enjoyed the benefit of a facility which provided employment and prosperity. Now, this installation has been closed, and it would be good that the activity that the mill previously undertook were compensated by new economic initiatives. Links with the term "radioactivity" persist, although this is more a problem of image than anything else. In any case, this connotation might complicate the development of new economic activities.

For this reason, I would like to underline the fact that dismantling of this type of installation should always go hand in hand with informative and socioeconomic measures explaining, exactly the environmental situation of the sites, in order not to jeopardize the development of new economic activities that might, at least, maintain the levels of activity and social welfare that existed when the plants were in operation.

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MILLING SITES REMEDIATION — ELEMENTS FOR A METHODOLOGY AS DEVELOPED IN FRANCE BY COGEMA

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Abstract

Compared to other metals, mining and milling of uranium generate specific potential hazards due to radioactivity. Remediation of the sites concerned and specially impoundments of mill tailings is a very important step of mining. We first remind the principles and objectives governing site remediation in France. Important steps of the methodology are reviewed: inventory (characterization of the waste products, location and tonnages), some studies which support the choice made for remediation techniques (mineralogical studies, leaching tests, hydrogeological, compaction, stability studies ...) and communication. Some of the cost estimated are mentioned: impact on the environment but also occupational exposure and of course financial costs of the operations. Since 1946 COGEMA has been prospecting, extracting and treating uranium ore first in France and then all over the world. Usually sites have been regularly remediated following closure. Due to general reduction of the uranium mining in France, remediation of the main impoundments has become a major concern in term of long term efficiency and financial costs. Consequently it is necessary to be aware of the different factors and to evaluate or measure the long term impact of each choice.

1. PRINCIPLES AND OBJECTIVES OF REMEDIATION

The main concern is long term public safety and health. In France the philosophy of environmental restoration fulfills the following general principles:

- Highest efficiency of the remediation action.
- Final impact of the site must comply with all French regulatory constraints especially rules concerning radiological impact.
- All types of residual impacts are made as low as reasonably achievable (ALARA). Concerning radiological impact, the basic principles of ICRP are applied: justification, optimization and limitation.
- Large information and participation of the public.

In this frame, the main objectives of site remediation are:

- long term stability of the remediated area in order to assure the confinement of the radioactive materials,
- prevention against human intrusion (for instance, the residues should never be used for construction),
- choice of natural barriers in order to rely on passive controls and reduce or suppress future technical supervision requirements,
- reduction of the total land consumption and the following need for institutional control,

- integration into the surrounding landscape; if possible, operator will try to match the wishes of the local or regional groups concerning future use of land (local needs for irrigation including water storage and supply, revegetation, hunting etc. .. are possible of the remediation is not affected),

- of course, the resulting project must be technically and economically workable.

1.1. Frame of the French regulation

General laws concerning Protection of Nature were published in 1976 among them the rules concerning Impact Studies which have to be carried on for every new project. Laws concerning Environment include special regulations concerning air, water as well as public inquiries.

The laws concerning ICPE (Classified Installations for Protection of Environment) set a frame for all industrial activities including wastes but radioactive wastes are considered apart.

In France, exploration, mining and remediation are controlled by the regional authority (Direction Regionale de l'Industrie, del a Recherche et de l'Environnement — DRIRE) within the framework of the French Mining Code. The impact study is compulsory for the rehabilitation of the site when it closes down. A specific impact study will be conducted for the remediation of an old mining or milling site which started before this type of study was compulsory. The environmental impact study includes the initial radiological state and the technical aspects of the remediation. Technical reports of impact studies are prepared and submitted to DRIRE and open to public inquiry. Final decision is signed by the prefect.

Radiation protection of the environment during and after mining is the purpose of Decree No. 90-222 dated 9 March 1990.

This decree was drawn up on the basis of the French mining code, Euratom directives, the French decree concerning the general principles of protection against ionizing radiations, itself based on the recommendations of the ICRP (International Commission on Radiological Protection) and the directives of the European Community. It was submitted for approval to the Central Service for Protection against Ionizing Radiations (Ministry of Health) and the General Council of Mines.

It forms the "ionizing radiation" section of the RGIE (General Instructions for the Mining Industry). The main quantified objective is the *Added Total Annual Exposure Rate* (ATAER or TAETA). The ATAER is determined from the measurements at the sire (with substraction of the natural background exposure) and from a realistic exposure scenario which is established for the population. This means that:

ATAER = $TAER_{(A)}$ Total annual exposure rate at the site
minus

$TAER_{(B)}$ Total (natural) annual exposure rate measured in the general region or established from analogous sites

$$ATAER = (TAER_{(A)} - TAER_{(B)})$$

must be less than 1 (the value of 1 corresponds to an exposure of 5 mSv/year).

TAER is calculated using the following formula:

$$TAER = \frac{\gamma}{5\ mSv} + \frac{PAE\ Rn222}{2\ mJ} + \frac{PAE\ Rn220}{6\ mJ} + \frac{IE\ Ra226}{7000\ Bq} + \frac{IE\ dust}{170\ Bq\ \alpha} + \frac{IE\ U238}{2\ g} \qquad (1)$$

γ	external exposure through gamma irradiation in mSv
PAE Rn222 PAE Rn220	potential annual inhaled alpha energy from short lived decay products of Rn220 and Rn222 in mJ
IE dust	total activity of long lived alpha-emitters of the U-chain, present in the air in the form of dust or in suspension, inhaled annually, in Bq
IE Ra226	internal annual exposure by ingestion of Ra226 (through water and the food chain) in Bq
IE U238	internal annual exposure by ingestion of U238 (through water and the food chain) in grams

2. METHODOLOGY

First of all an inventory is necessary: assessment of the wastes which have to be handled, their location and quantities. Studies allow a better understanding of the wastes, their possible evolution and the relationship between the impoundment and the environment. Applied studies lead to the definition of procedures for the remediation actions.

2.1. Different types of waste products

The main types of products are:

- pit run rocks and stockpile of poor ore;

According to the type of ore treatment, two main categories of wastes are produced:

- heap leaching wastes resulting from low grade ores which were usually sprayed with acid without any crushing;
- mill tailings disposed of in settling ponds after neutralization: they are fine grained ($< 500\ \mu$) but have low permeability;
- other wastes are the materials resulting from the dismantling of the facilities; their activity is low and they represent less than a percent of the initial activity of the ore treated;
- waste waters coming from the different type of wastes;
- sludges resulting from the treatment of waste waters which might last after the end of activity.

2.2. Different types of sites — tonnages

Years of uranium mining by COGEMA and subsidiaries have lead in France to:

- more than 200 mining sites, three fourth of them being more than an hectare; either open pit or underground, we have to deal with the associated waste dump;
- 11 industrial sites where operations were mill or heap leaching;
- 22 storage sites for the residence of ore treatment residues.

The total area for the industrial sites and the associated impoundments ranges from 3 hectares to more than a hundred. Due to the very low grade of uranium which were treated in France (average 0.15% U or 0.23% U if heap leaching is excluded) more than 99% by weight goes to waste and very important tonnages have to be dealt with. By the end of 1993, a total of nearly 50 million tonnes has been accumulated.

Dismantling of a mill leads to several thousands of tonnes of slightly contaminated concrete debris and scraps. The most contaminated equipment being those for attack and resin extraction. The estimated activity included in the calculated activity of the impoundment.

The types of storages are well known. Either piles of heap leached ores or impoundments of mill tailings. Impoundments are limited by dykes or fill an open pit (Fig. 1).

2.3. Mineralogical residues and geochemical characterization and studies

The main concern in this presentation are the residues coming from treatment of uranium ore.

However, characterization of the materials used for a solid cover of the residues is also necessary although French ores are usually low in pyrite content and stripping materials do not lead to acid mine drainage problems.

The mineralogical content of the residues is the original association of quartz, feldspar and aluminosilicates (for granites) as well as carbonates, metal oxides and hydroxides and secondary sulfates resulting mainly from neutralization.

Radionuclides are all natural and correspond to the decay products of U238, U235 and a little Th232. Due to uranium extraction with a mill recovery ranging from 92 to 97%, total radioactivity of the waste is about 70% of the original ore. Average total specific activity of the mill tailings is 300 $Bq.g^{-1}$ and around 20 $Bq.g^{-1}$ for Ra226 alone pH is a matter of concern mainly for heap leaching residues which usually have been only flushed with weak acids and water at the end of the U extraction. (See Table I).

Study of the physical characteristics (par. 2.6.1. and 2.7.2) of the residues is the first stage for the different geotechnical studies (settlement, compaction, stability).

The main facts from detailed mineralogical and geochemical studies are:

- important enrichment in Ra226 in the fraction less than 28μ;
- difference between mill tailings issued from sedimentary carbonatic ores (ex. Lodève) and granitic ores; in Lodève Ra226 seems to be fixed but residues issued from acid mill leaching show a significative redistribution of trace elements (As - Cu - Fe= Pb) and radionuclides (Ra226, Pb210);

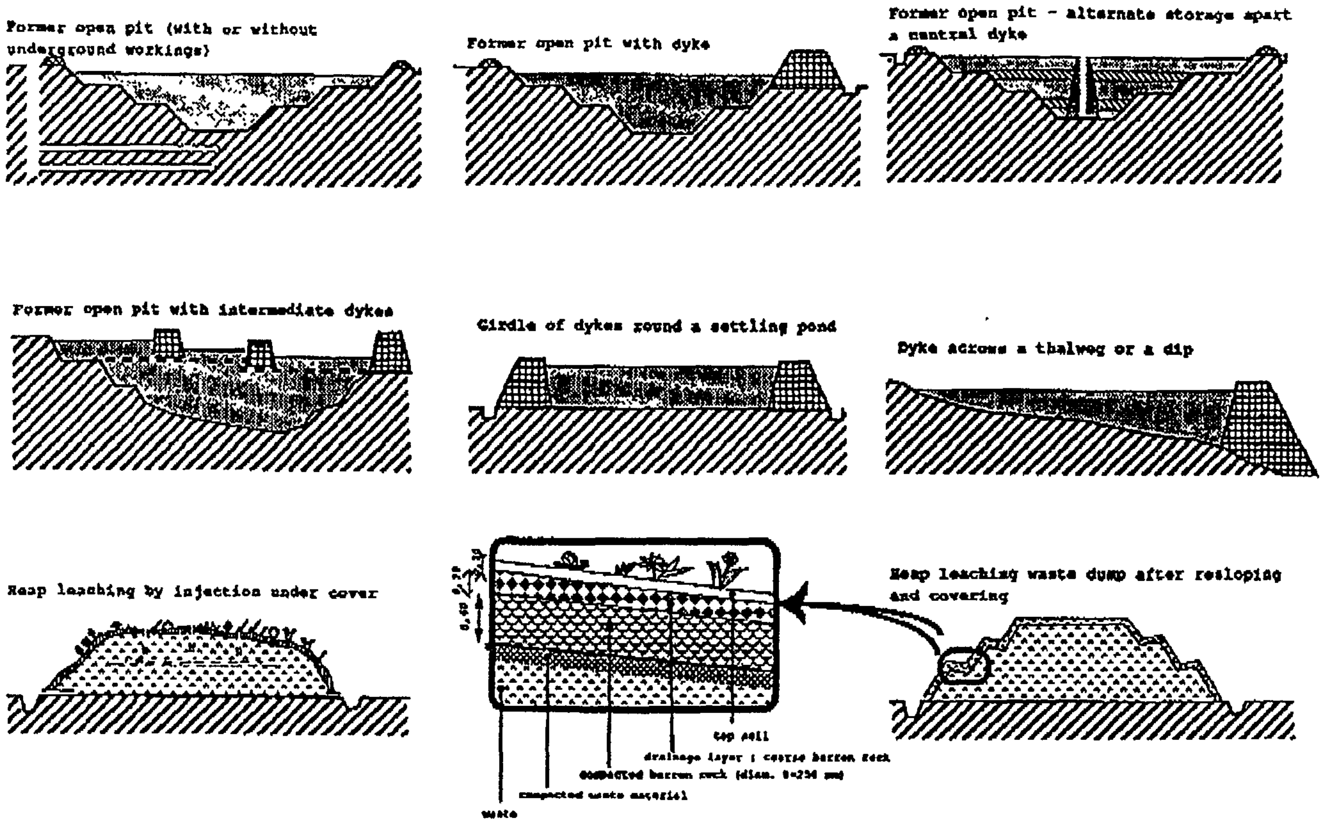
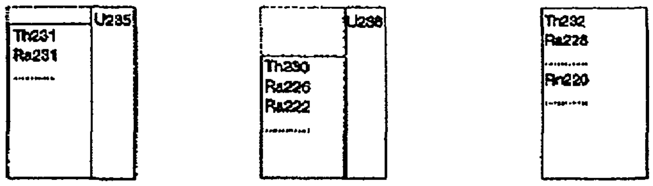


FIG. 1. Different types of impoundments.

TABLE I. CHARACTERISTICS OF WASTE PRODUCTS FROM TREATMENT OF URANIUM ORES

	HEAPLEACHING WASTES	MILL TAILINGS
U ore grade	0.15 - 0.6 ‰	1 to 10 ‰
Particle size	Crushed or not : < 500 - 1000 mm	D80 < 450 μm
Weight	100 % of original ore	= 110 % of original ore
Residual U	20 to 40 % of original ore	3 to 10 % of original ore
SITUATION IN 1992 Number of sites Tonnage (10^6t)	22 18	 29
RADIONUCLIDES		
Activity Ra226	= x ‰U grade x 12.4 Bq.g^{-1} 2 to 7 Bq.g^{-1}	Average 20 Bq.g^{1}
Total Massic Activity	Average 40 Bq.g^{1}	Average 300 Bq.g^{-1}
Radiological concern	Gamma exposure Rn222 exposure Transfert of radionuclides (U - Ra) in water	
Other chemicals	pH - Dissolved salts (SO_4 , HCO_3) - (heavy metals)	

- secondary information of minerals (gypsum and argilous minerals) which tend to be more important from the top to the base of the pile of residues (Somot S, and all 1994);
- very limited migration of radium in the granitic or sedimentary basement of our impoundments.

These observations allow us to conclude that residues are not fixed entities but are submitted to diagenetic phenomena which may contribute to fixation and retention of heavy metals and radionuclides.

2.4. Leaching tests

Components of the residues have gone through the strong chemical attack of the ore. Nevertheless, further leaching tests can quantify the residual ability of the materials to release potential pollutants (radium, uranium, metals of acid in case of potential AMD for any pit run lock).

We have used dynamic leaching tests acceding to the French norms (AFNOR X 31.210 - L/S = 10) extended up to ten successive extractions (L/S up to 300).

The main conclusions for granitic ore residues after acid treatment are:

- leached radium is linked first to solubilization of gypsum then to baryum minerals,
- total leached radium is limited to a small fraction of the initial quantity in the residue,
- leaching of radium is less efficient with stocked residues than with fresh,
- quality of leachate is never higher than a few Bq Ra226/l,
- metals and uranium do not move during these tests.

The same experiment conducted with sludges produced by the treatment of Le Cellier waste waters (BaCl2 for radium, lime for U and pH control, floculants) give the following results:

- small quantities of uranium (less than 2%) and radium (less than 0.1%) removable with fresh water; metals non detectable,
- leaching with on site radioactive water show absorption of the incoming radium.

Leaching test an petrographic studies support the idea of a weak provisional impact of the milling activity through the impoundments.

2.5. Hydrogeology

Alteration of granitic basement lead to superficial disconnected aquifers. Permeability of argilous altered granite are usually low (10^{-8} m.s^{-1}) and are a good natural water tight layer for impoundments.

Deeper permeability is linked to the fracturation of granite and the "connection index" of the fractures. Permeability can be as low as 10^{-10} m.s^{-1} 300 m deep with poor drainage capacity.

Correlation between flow of mine dewatering and rain, water quality around the sites and detailed hydrogeological studies usually conclude to:

- direct feeding of the mine by superficial water,
- no direct link between mine waters, the near impoundment site or superficial neighbouring springs.

The impoundment is a pile of argilous material with poor permeability ($< 10^{-7}$ m.s^{-1}) which allows a theoretical very low rate of water renewal in the residues (up to one every ten years).

Accordingly risks of groundwater pollution through seepage of the impoundment are limited.

Hydrogeological studies will predict the location of future springs of seepage water and the best locations for water monitoring stations.

2.6. Settlement of the residues

2.6.1. Geotechnical characteristics of the residues

Main characteristics necessary to assess the possible evolution of the materials are:

			RESIDUES
		ECARPIERE	Possible range
Grain size	% < 500 μ	100	100
	% < 80 μ	80	40 - 100
Water content	w%	35 - 130	25 - 130
Dry specific weight	$T.m^{-3}$	0.6 - 1.2	0.6 - 1.3
Consolidation	Cv $cm^2.s^{-1}$	$6.5 - 10^{-3}$	$10^{-5} - 10^{-2}$
Cohesion	Cu $T.m^{-2}$	0.5 - 8	
Permeability	K $m.s^{-1}$		$< 10^{-7}$

2.6.2. Settlement

Observation of the surface of dewatered impoundments show vertical cracks with stairs: this is the result of settlement (self compaction) by natural dewatering. Results from Ecarpière with low density of the residues, getting higher with depth, degree of consolidation lowers down to 30%, confirm that natural compaction of the impoundment is not finished. In this case, settlement compaction was predicted to reach up to 5 m, which should need 25 to 30 more years, for the thickest part of the impoundment (40 m).

Of course, the final compaction shall be reached earlier by technical dewatering. In order to link the sand lenses and enhance drainage, vertical drilling (and pumping?) can be used. In the case of Ecarpière 90% of final compaction could be reached in a six months time.

2.7. Cover for the residues

2.7.1. Objectives

A cover should first enhance protection of the impoundment: that is radiological and mechanical protection (erosion). The cover must also limit infiltration of rain water and allow their selective drainage. The topographic modelling of the final cover will allow landscape integration of the remediated site.

2.7.2. Characterization of materials for covers

Apart from petrographic, chemical and radiological characteristics which have to be in accordance with the general objectives of the remediation, geochemical characteristics shall be assessed.

Here are some measures gained during the study for the Ecarpière project.

		Altered gneiss	Heap leached ore
Grain size	max. mm		60 -150
	< 80 μ%		6 - 12
Water content	w%	5 -16	5 - 8
Dry specific weight	$kN.m^{-3}$	19.5	20
Permeability	K $m.s^{-1}$		
	non compacted	1.21 10^{-4}	8.4 10^{-5}
	after compaction	3.0 10^{-7}	2.5 10^{-8}

2.7.3. Compaction and test plots for cover

Objects listed earlier can be enhanced through compaction. According to different test plots implemented:

- permeability can be reduced two or three order of magnitude by compacting,
- one meter of non compacted material (barren gneiss) is equivalent to 0.5 m of the same compacted material,
- radon flux were reduced by 82% while gamma radioactivity is 70% lower.

Tests show that heap leached materials (compacted or not) have lower permeability than the original ore: thus is a good source of materials to cap mill tailings impoundments.

2.8. Stability

Stability problems are linked to the following aspects:

- lateral containment of the residues (as written earlier impoundments are often limited by dykes),
- disposal of the cover for mill tailings,
- stability of piles of heap leached residues and their cover.

In all cases the general procedure is:

- geotechnical characterization of the different materials (see 2.6.1. and 2.7.2.),
- water pressure inside the materials,
- calculation of the stability coefficient according to FELLENIUS or BISHOP who give a good evaluation of the constraints along the breaking-down circle,
- these methods can take into account the horizontal static added effort linked to the most likely earthquake.

According to the long term stability it is assured if the coefficient reaches 1.3 to 1.5 and in any case remains higher than 1, especially in the case of an earthquake.

2.9. Surface hydrology — erosion and seeding

Three main origins of flows must be estimated and separated:

- external non contaminated water which will have to be diverted around the site,
- surface running water which requires only a settling pond and control before being released,
- seepage water coming out of storage sites which must be treated for pH and/or for U and Ra content.

In order to control surface erosion it is suggested to:

- avoid steep slopes, unless specially designed, and organize a network of small water basins able to cope with possible floods,
- allow surface infiltration by engineering a multilayer cover with a compacted layer buried under a loose upper coat,
- have a quick vegetal coverage of the surface which will prevent direct impact of rain drops, slow down the rainwater flow and trap small particles.

2.10. Water treatment

After remediation, settlement of the materials, soaking of the different impoundments produce a continuous flow of water cannot be released to the environment. If collected separately the flow of water needing treatment can always be adjusted to the evolution of its quality.

The former water treatment plant must go on operating, often it will be rebuilt near the lowest water collecting point of the site.

2.11. Monitoring

The monitoring network which has been going on all through the operation and site remediation must be adapted to the situation after remediation.

2.11.1. Geotechnical monitoring

If containment is linked to the stability of a dyke, controls will include:

- topography measurements
- measurements of water levels in piezometer holes,
- measurements of water flows in drains and leaking points,
- visual inspection of the site.

2.11.2. Radiological monitoring

According to the specific risks of the site, waste water and stream water are sampled for chemical analysis and suspended solids, also water from piezometer holes.

For radiological monitoring, the network must take into account the critical groups, that is the population living near the site. Monitoring stations must include devices for water sampling or air sampling.

Air monitoring stations are equipped with:

- small sedimentation plates for airborne dust measurement,

- thermoluminescent dosimeter for external irradiation measurements (gamma radiation),

- CRPM (Centre de Radioprotection dans les Mines) integrated site dosimeter measuring:

  - potential alpha energy (PAE) from radon short live daughter products,
  - alpha activity of airborne dust particles.

On top of those continuous samplings and measurements, periodic analyses are made in the food chain.

2.12. Communication

As provisioned by law, the projects have to be submitted to the authorities and to the public. The authorities give the final authorization after the public inquiry. However, this is not enough an the legal frame should be completed by regular information of the public and this may contribute to anticipate objections.

Results of the environmental monitoring are regularly sent and explained to mayors and town councillors or can be explained to local commissions. Direct information of the public is part of a long term project:

- sites open to visits (schools, relatives of the workers, ...),

- regular publication of information sheets sharing news of the site activity, explaining radioactivity and the environmental monitoring,and giving the last measurements. Distributed in public halls and in shops, they can be mailed free of charge to those asking for it,

- brochures explaining technical matters are planned.

Of course, QUALITY of remediation work goes through information of the team in change of the job. This is easier and better when it is done by the former miners who were already concerned by quality during extraction.

2.13. Main options for remediation — implementation

According to the results of the different studies described earlier, details of the remediation project will change from site to site but two main options can be distinguished according to the cover chosen:

- wet option with a water cover,
- semi dry option if a solid material cover is implemented.

Although one site (Le Fore) is for the moment under water, the second option is favored in France.

For good results implementation needs:

- a special team with appropriate equipment,
- a strict topographical and radiological follow-up.

The principal stages involved in implementing the remediation are as follows:

- drawing of the project: topographic modelling will link landscape integration of the remediated site, technical constraints for slopes, water and road networks, calculation of the different volumes to push, load and carry, ...;
- dismantling of the mill; contaminated equipment is placed with the residues;
- cleaning up of the site for gathering of the products in the main impoundment;
- backfilling, earthmoving, caping, compacting and resloping is the biggest part of the job in term of spendings;
- finishing works include water treatment, plant, ditches, roads, all installation of monitoring equipment, revegetation and signalization;
- controls to check effectiveness and quality as regards stability, drainage, radioactivity;
- gather experience for new projects.

3. FIGURES ABOUT SOME COSTS

Remediation of mining and milling sites induces certain costs. Apart from the direct expenses linked to the studies and field work, occupational exposure and the impact on the environment should be considered.

3.1. Occupational exposure

As part of the total "cost" of the remediation, personnel dosimetry of the members of the team in charge of the operation should be as efficient as before. In Ecarpière remediation of the open pits followed by that of the impoundment was operated by part of the personnel formerly in charge of the open pit extraction. Average exposure is slightly lower during remediation (about 20% for a total exposure less than 1 mSv/year) than during the phase of extraction.

3.2. Impact on the environment

The following table (Table II) gives the order of magnitude of the different exposure factors comparing the levels for natural background and the nearby areas surrounding the sites. Considering the minimum and maximum values of the different factors, the added exposure is a maximum of 3 mSv, which is within the regulatory limit (5 mSv for the public).

TABLE II. ORDER OF MAGNITUDE OF DIFFERENT FACTORS OF EXPOSURE (in equivalent mSv[1]).

	NATURAL BACKGROUND LEVEL FRANCE				NEARBY AREAS SURROUNDING MINING AND INDUSTRIAL SITES (1991)			
	%	Min		Max	%	Min		Max
Gamma	57	0.75	to	1.96	47	0.84	to	2.73
Rn222	25	0.32	to	1.81	24	0.29	to	2.38
Rn220	4	0.06	to	0.11	4	0.06	to	0.11
Dust	5	ns	to	0.16	4	0.16	to	0.31
Soluble U	9	ns	to	0.20	21	0.20	to	0.20
Soluble Ra		0.01	to	0.07		0.06	to	0.20
Fluctuations for total exposure (considering individual stations)		1.92	to	4.26		2.26	to	6.07
Average for background stations of CRPM			2.24					

The main problem is the evaluation of the natural background levels before activity started on the site. Considering that natural variation ranges from 2 to 4 mSv (even 6 if radon indoor is considered), one can imagine that it will be difficult to certify an added exposure limited to 1 mSv as recommended by ICRP 60.

However, a comparison between total exposure on an operating site (Herault) and a remediated site (Le Cellier in Lozère) shows a significant decrease as the added exposure is also decreasing. After remediation the added exposure is negligible (Fig. 2).

In the environment of our sites, the air and water pathways represent nearly 100% of the radiological impact. Analysis in the food chain (vegetables, grass and milk and the associated soil) show very little difference between samples collected up and downstream of impoundments.

In France, analysis and results of radiological monitoring are certified by ALGADE/CRPM (Center de Radioprotection dans les Mines) and sent to regulatory authorities (DRIRE and SCRPI = Ministry of Health).

3.3. Elements for financial costs

3.3.1. Team and equipment

The mill of Ecarpière which produced (mill and heap leaching) 14 000 t of uranium from 1957 to 1991 is now under remediation with very long haulage distances (average 2 km). It is planned to move about 3 million cubic metre of material in three years time. The team consists of altogether 40 people, among them 20 engine drivers divided in two shifts.

[1] according to ICRP 26

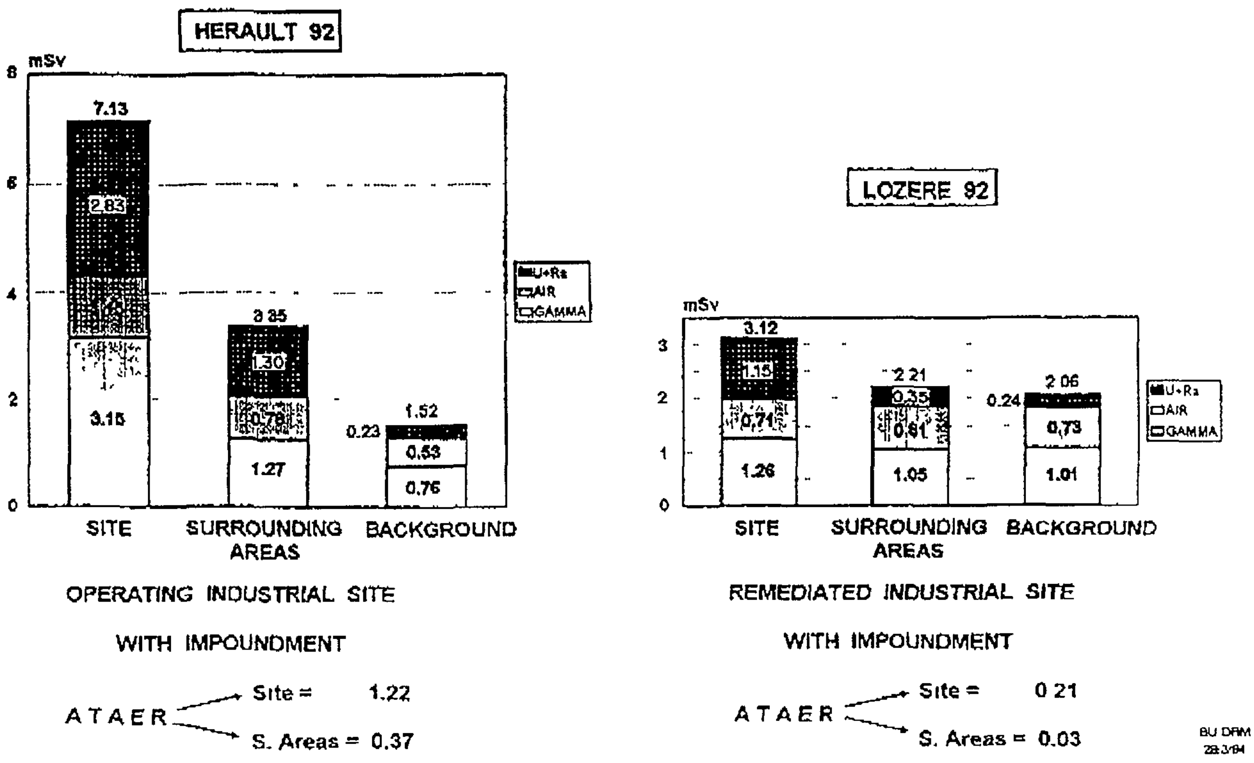


FIG. 2. Results of remediation.

3.3.2. *Costs*

Expenses for site remediation of mill installations/mill tailings storage range from 600 to 1100 kF an hectare. Dismantling of the mill itself costs around 15 to 20 000 kF.

Total cost for an average lot producing more than 1000 t U/year (mining sites and a mill) ranges from 8 to 13 F a kg U (depending on the size of the site).

These costs split into:

- studies: 5%
- earth moving: 70%
- finishing works: 10%
- revegetation: 5%
- controls: 10%

4. CONCLUSION

Site remediation has always been part of COGEMA's and its subsidiaries' activities. As for industrial sires, six out of the eleven sites mentioned earlier have been completely remediated between 1980 and 1991. Only two mills will remain operating at the end of 1995.

Site remediation is very expensive and has to be carefully studied and planned in order to apply the general principles on a site specific basis. Usually:

- the wastes which have to be managed after uranium extraction represent very large volumes but they have low initial specific activity and low reactivity;

- impact on the environment due to good confinement and stability of the impoundment is limited;

- on the site remediation work can efficiently reinforce the system for the long term.

Stability calculations take into account a seismic event. Moreover the provisional radioactive impact is conforted by the natural evolution of the residues.

At the end of the remediation:

- operators shall remain owner and responsible of the site,
- operator goes on measuring its radiological impact on the environment,
- if necessary, the operator treats the remaining flow of water.

In order to keep a long term memory of the sites, a double institutional control is set in France:

- restricted use of the sites is attached to the land, recorded by the "Conservatoire des Hypothèques" and shall be transmitted to the new owner in case of sale,

- a national agency is in charge of a record of all low radioactive storage sites including mill tailings.

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IMPACT OF URANIUM MINING AND PROCESSING IN NORTH BOHEMIA ON CONTAMINATION OF THE PLOUČNICE RIVER BASIN BY RADIOACTIVE MATTER

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Abstract

The River Ploučnice has been loaded with the uranium ore mining and processing wastes water since 1966. Waste water exhibited an increased radium-226 and uranium concentration in dissolved as well as suspended matter. The modern waste water treatment plant has been operated since 1989. The results of the detailed field study on contamination of the river water, interstitial water, bottom sediment, flood area with radioactive matter provided in 1986-1992 are presented. The transport rates of radium in dissolved and suspended matter has been studied under the conditions of artificial flood using water accumulated in the Horka dam. Contamination of the soils with radionuclides in flood area, using the dose rate was measured.

1. INTRODUCTION

For more than twenty years, the Ploučnice River has been unfavourably affected by mining of radioactive raw material in the area surrounding the Stráž pod Ralskem municipality. For mining purposes, pit water had to be pumped out, containing excessive amount of radioactive substances, radium-226 in particular, in both dissolved and suspended forms. The effectiveness of radioactive substances removal by a provisional pit water treatment plant, which had been in operation until 1989, was approximately 90% [1, 2]. Water quality of the Ploučnice River and also sediments and biomass were unfavourably affected by suspended particles, namely by the radon-barium sulfate precipitate with high specific content of radium-226.

The waste water was drained into the Ploučnice River by a channel with an outlet situated upstream of the Stráž pod Ralskem municipality (see Fig. 1). The long-term average waste water discharge was 500 $l.s^{-1}$. Fig. 1 shows also sites where samples have been regularly collected since 1966 [3] for monitoring of radioactive substances content, unfortunately by using filtrated samples only (in dissolved form). Fig. 2 shows an example of a relationship between the radium-226 annual average concentration in dissolved form and annual average discharge at the Noviny sampling point on the Ploučnice River in the period 1966-1988. It can be seen that the radium-226 average concentration had slightly increased during the period until approximately 1985 and then it decreased, as discussed in a greater detail below. Relevant studies from the period 1971-1978 [4, 5, 6] indicated significant ratio of radium-226 in suspended form and presence of radon-barium sulfate. Specific content of radium-226 in the precipitate of the radon-barium sulfate, which was separated from bottom sediments of the Ploučnice River, was around 3 $kBq.kg^{-1}$ of barium [7].

2. ASSESSMENT OF RESULTS

2.1. Water

Based on the above results, a detail regular sampling programme was carried out in the period 1986-1992 in order to increase the knowledge on the processes of radioactive substances contamination of the Ploučnice River basin, including sediments and soils in the flood plains. In this

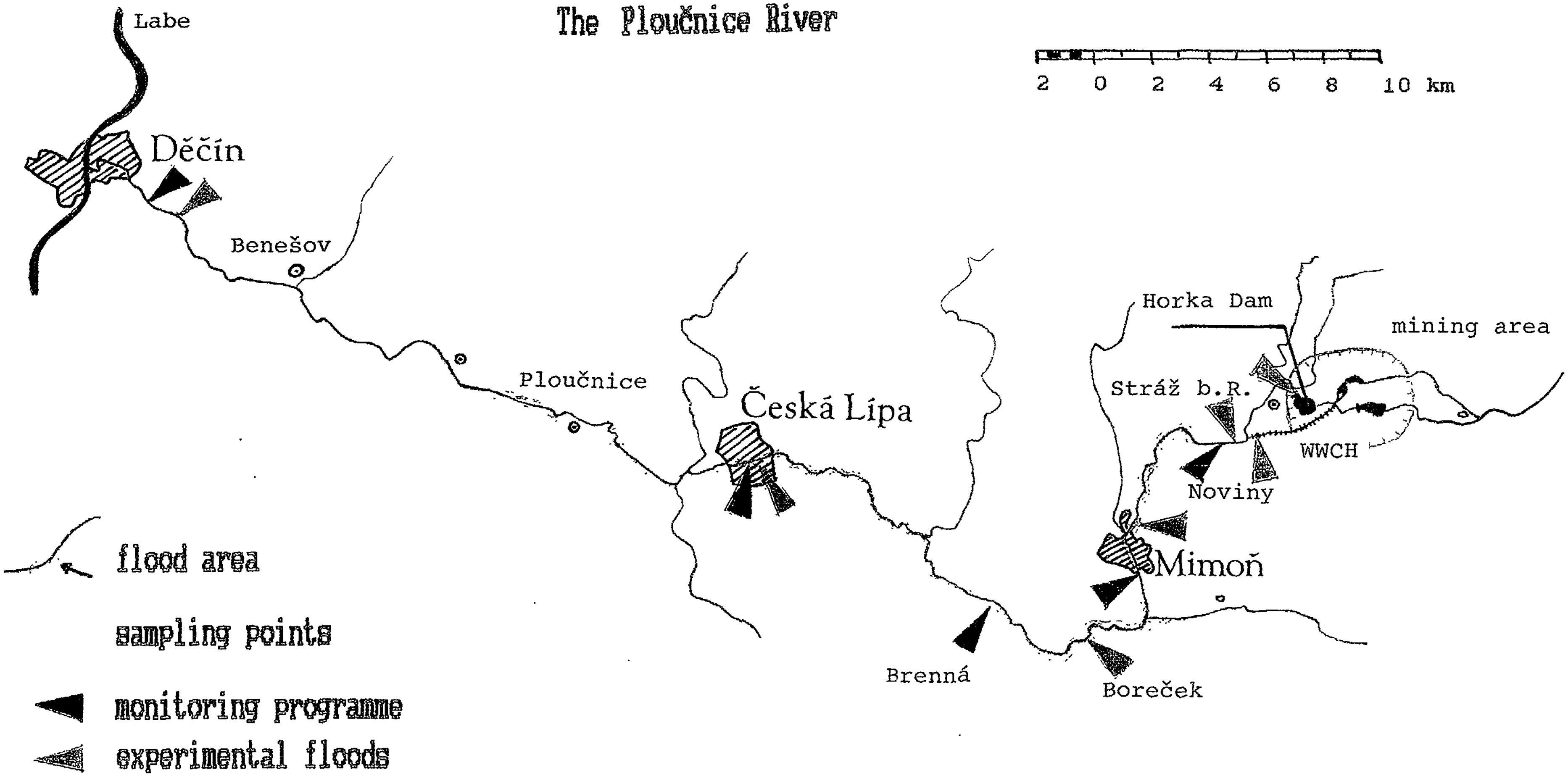


FIG. 1. The Ploučnice River.

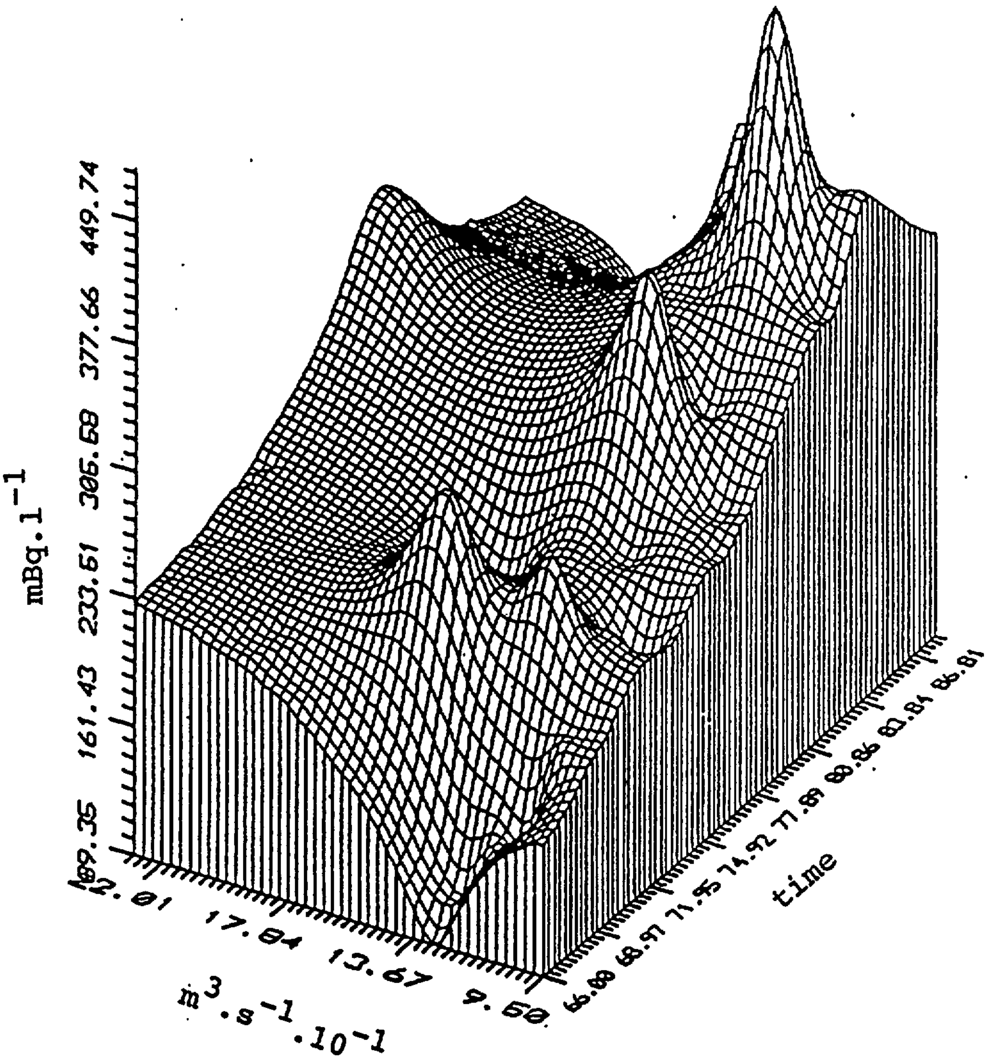


FIG. 2. Radium-226 annual average concentration (mBq/l) since 1968.

project, the T. G. Masaryk Water Research Institute cooperated with the Ohře River Water Authority in the Chomutov municipality and its branch in the Terezín town, with the Radiochemical Laboratory in the Teplice municipality, and with the polluter, the former Czechoslovak Uranium Mines (now the DIAMO state corp.), Stráž pod Ralskem.

In addition to the sampling points shown in Fig. 1, the water samples were taken from the main tributaries of the Ploučnice River in order to determine background (natural) concentration of radium-226 and uranium-238.

For the period 1986-1992, an example of the variation of the radium-226 annual average concentration (including natural background concentration) along the Ploučnice River is shown, with respect to a distance from the waste water outlet, in Figs 3 and 4, considering dissolved substances and suspended particles respectively. A power function of the $a_v = a \cdot L^b$ type (where a and b are the parameters) approximates satisfactorily the relation between the radium-226 concentration (a_v) and the distance (L). A relation between the radium-226 concentration and runoff in particular sampling points was not determined as significant [8].

Figs 3 and 4 show a distinct decrease of the Ploučnice River pollution by the radioactive substances during the period 1986-1988, further significant improvement in consequence of operation

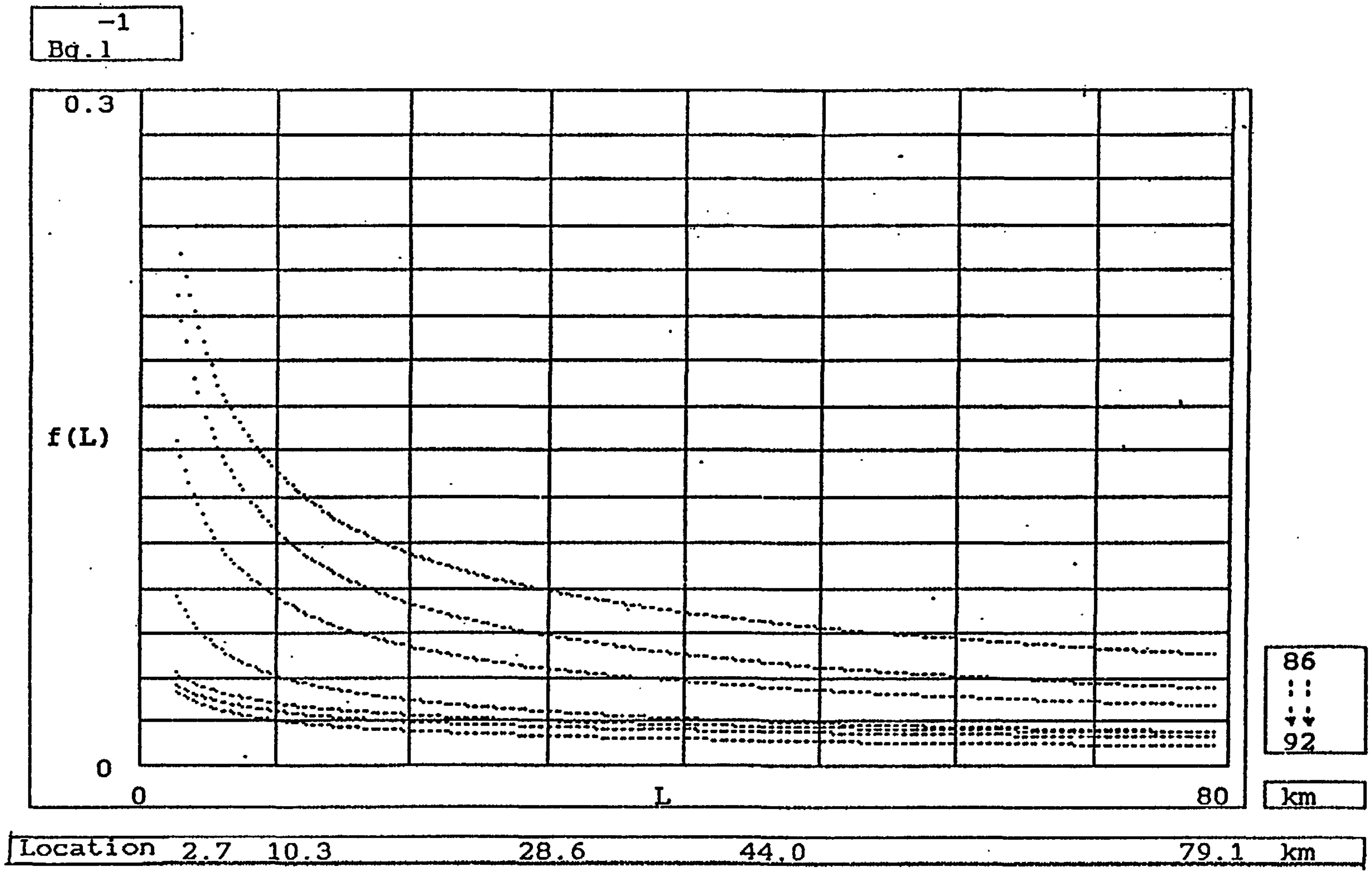


FIG. 3. Radium-226 concentration in the Ploučnice River, dissolved substances, annual averages 1986-1992.

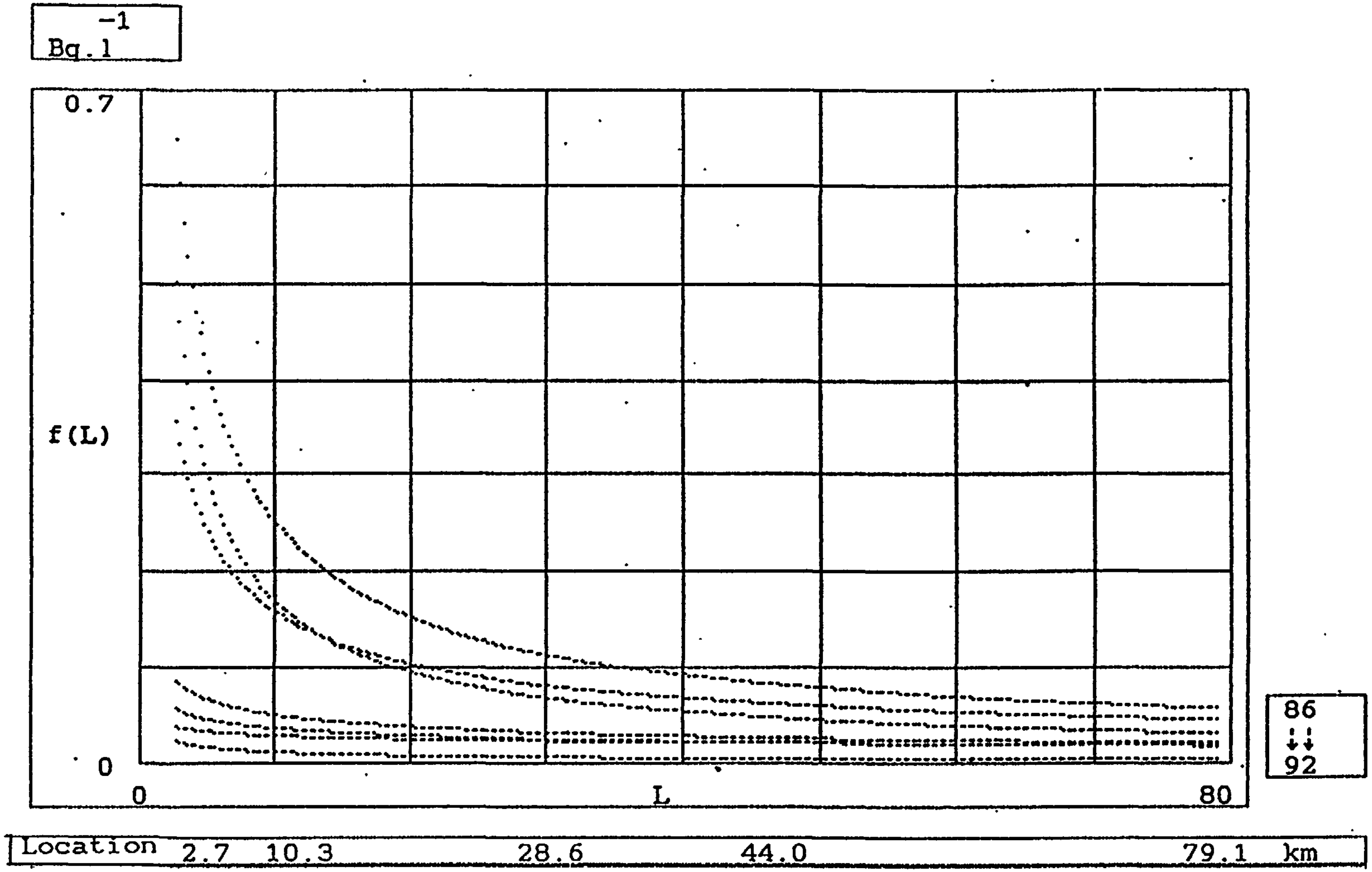


FIG. 4. Radium-226 concentration in the Ploučnice River, suspended particles, annual averages 1986-1992.

TABLE I. TOTAL RUNOFF OF RADIUM-226 IN DISSOLVED AND SUSPENDED FORM IN THE PLOUČNICE RIVER BETWEEN THE WASTE WATER OUTLET (NOVINY) AND THE RIVER MOUTH (DĚČIN).

Sampling point	annual average discharge	DM	SM	DM	SM	total
				cor. on background		
1986	$m^3.s^{-1}$	$GBq.r^{-1}$				
Noviny	1.52	10.2	23.1	8.5	22.1	30.6
Mimon	2.54	11.0	30.1	8.2	28.5	36.7
Brenna	3.48	11.9	15.9	8.0	13.7	21.7
Ceska Lipa	6.11	12.3	15.0	5.6	11.2	16.8
Decin	10.12	13.4	14.4	2.2	8.0	10.2
1990	$m^3.s^{-1}$	$GBq.r^{-1}$				
Noviny	1.40	1.5	2.8	1.1	2.5	3.6
Mimon	2.35	1.7	1.9	1.1	1.4	2.5
Brenna	3.21	2.3	3.2	1.5	2.5	4.0
Ceska Lipa	5.10	2.7	3.9	1.4	2.7	4.1
Decin	8.69	2.7	4.4	0.5	2.5	3.0

of a new Central Decontamination Station (CDS) that started at the beginning of 1989 and the following slight improvement until 1992.

By using radium-226 average concentration in both forms and the mean annual runoff of the Ploučnice River at the sampling points, the total load of the radium-226 was calculated for particular years. The results were adjusted by the difference between radium-226 average concentration of the Ploučnice River and of its tributaries. Table I gives amounts of radium-226 in 1986 and 1990. From comparison of the adjusted radium-226 amounts, a distinct uptake of the radium-226 is apparent, mainly of its suspended form, in the period before the CDS operation. In 1990, which characterizes situation after putting the CDS into operation, the adjusted amounts of radium-226 in dissolved and suspended forms are practically equal for all sampling points, taking into account the confidence interval of the radium-226 annual average concentration.

It follows from the assessment of the radium-226 loads along the Ploučnice River that radium-226, accumulated in the basin during the whole period of the operation of the uranium mining industry, is relatively strongly bonded. Taking into account the content of the radioactive substances, the water quality of the Ploučnice River significantly improved after reducing the river load by operation of the Central Decontamination Station. As the radioactive substances accumulated in the Ploučnice basin are strongly bonded, the rate of the solid matter decontamination cannot be reliably

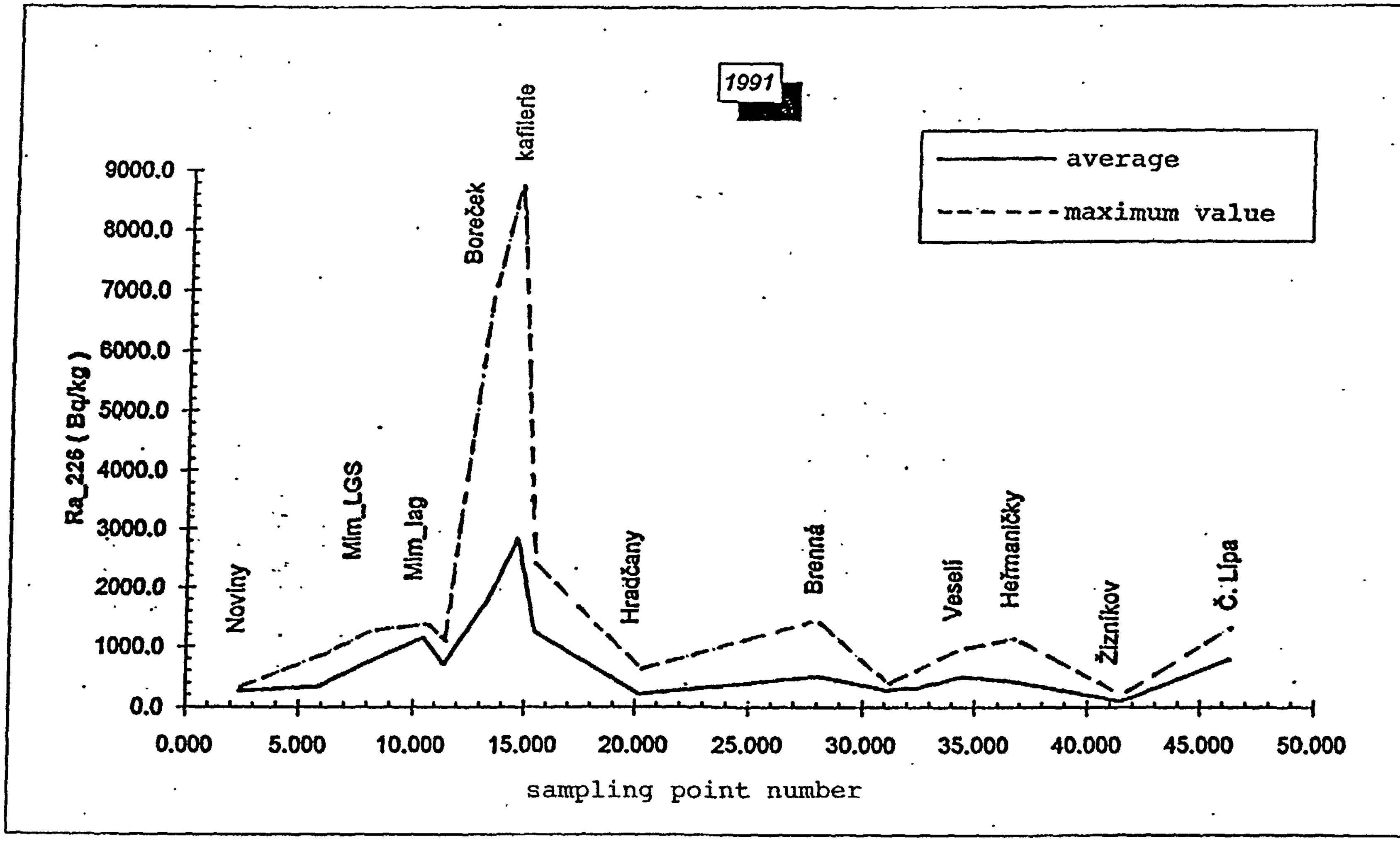


FIG. 5. Radium-226 concentration in bottom sediments.

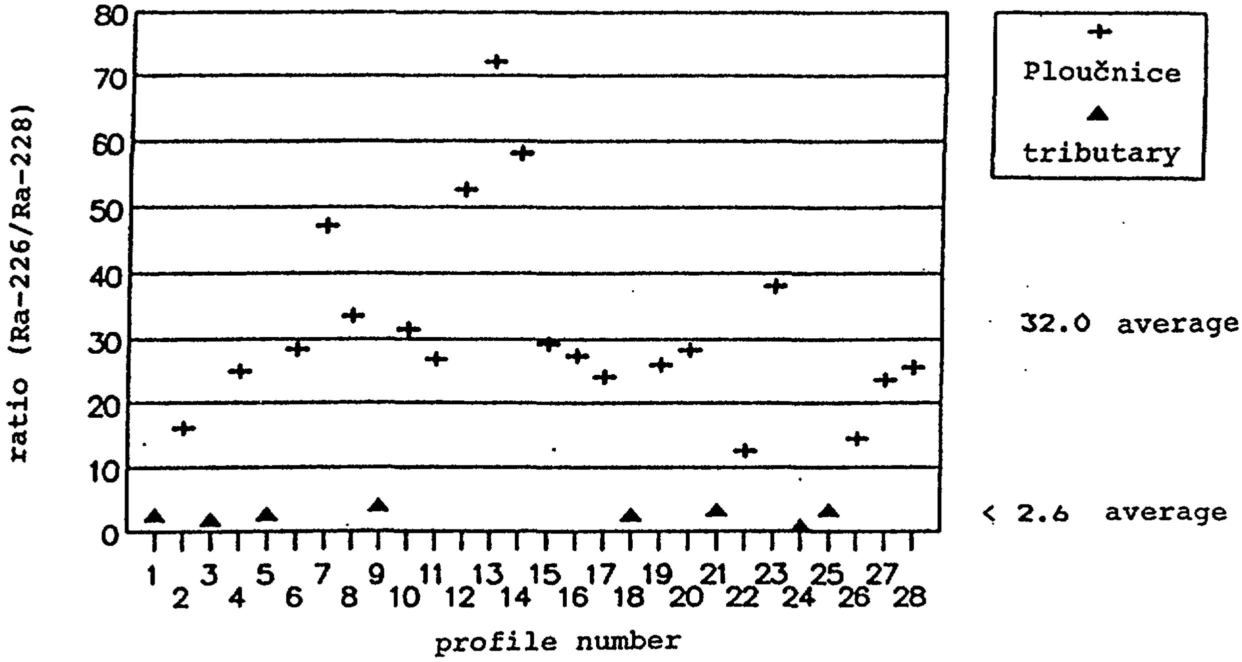


FIG. 6. Ratio of the radium-226 and radium-228 concentration in bottom sediments of the Ploučnice River and its tributaries, 1991.

predicted by using methods based on budget assessment of radioactive substances in water and suspended particles. Generally, it can be assumed that the decontamination process of the basin as a whole is very slow. Similar results have been found for uranium or uranium-238.

2.2. Bottom sediments and interstitial water

The studies on accumulation of the radioactive substances in the Ploučnice River basin continued by carrying out the observation of the specific concentrations of the radioactive substances in bottom sediments of the affected reaches of the Ploučnice River and its tributaries free of radioactive contamination. In addition to taking global samples representing approximately 30 cm deep layer of the bottom sediments in the longitudinal profile of the Ploučnice River, vertical samples were collected and the content of radioactive substances was analyzed for particular grain fractions of the bottom sediments.

Similarly as in case of water samples, the contamination of the bottom sediments is illustrated by an example of specific radium-226 concentration along the Ploučnice River between the outlet of the waste water from the uranium mining and the Česká Lípa municipality (see Fig. 5). The figure shows an average and the maximum radium-226 concentration related to the weight of the dry sediment (105°C) and calculated from all samples collected at a river cross-section of the particular sampling point. The highest specific concentration was found in the section between the Mimoň and Hradčany localities were the river meanders and its slope is at its minimum. These results are in good conformity with those published abroad, where the highest specific concentration was determined in relation to hydraulic conditions in order to find river reaches suitable for sedimentation of fine-grained fractions of suspended sediments [6].

Interstitial water was collected at sites of vertical sample collection of bottom sediments. Table II gives an example of radium-226 and uranium-238 content in the interstitial water at the

TABLE II. RADIUM-226 AND URANIUM-238 CONCENTRATIONS IN THE INTERSTITIAL WATER.

Sampling point			Date	Uranium U_{nat}	Radium-226 ^{226}Ra
				$mg.l^{-1}$	$Bq.l^{-1}$
Ještědka River (background)	1 - 5 cm	J-IV/1	5.11.1992	0,0044	0,016
	5 - 10 cm	J-IV/2		0,0050	0,017
	10 - 20 cm	J-IV/3		0,0032	0,010
	20 - 30 cm	J-IV/4		0,0038	0,024
Ploučnice River downstream of Mimoň	0 - 1 mm	M 1	24.-28.8.92	0,0154	0,135
	1 - 10 mm	M 2		0,0204	0,140
	1 - 3 cm	M 3		0,0083	0,090
	3 - 5 cm	M 4		0,0105	0,140
	5 - 10 cm	M 5		0,0083	0,115
	10 - 20 cm	M 6		0,0143	0,190
	20 - 30 cm	M 7		0,0149	0,295
				~~0,0110~~	~~0,410~~

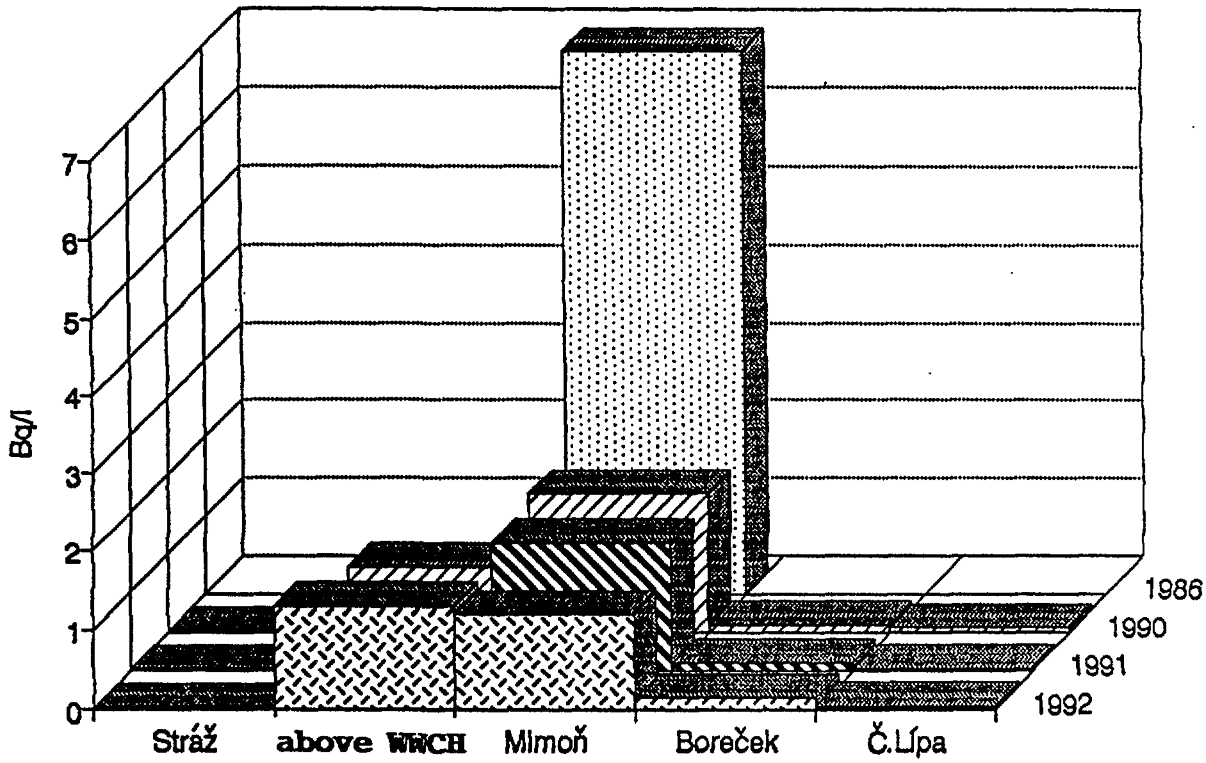
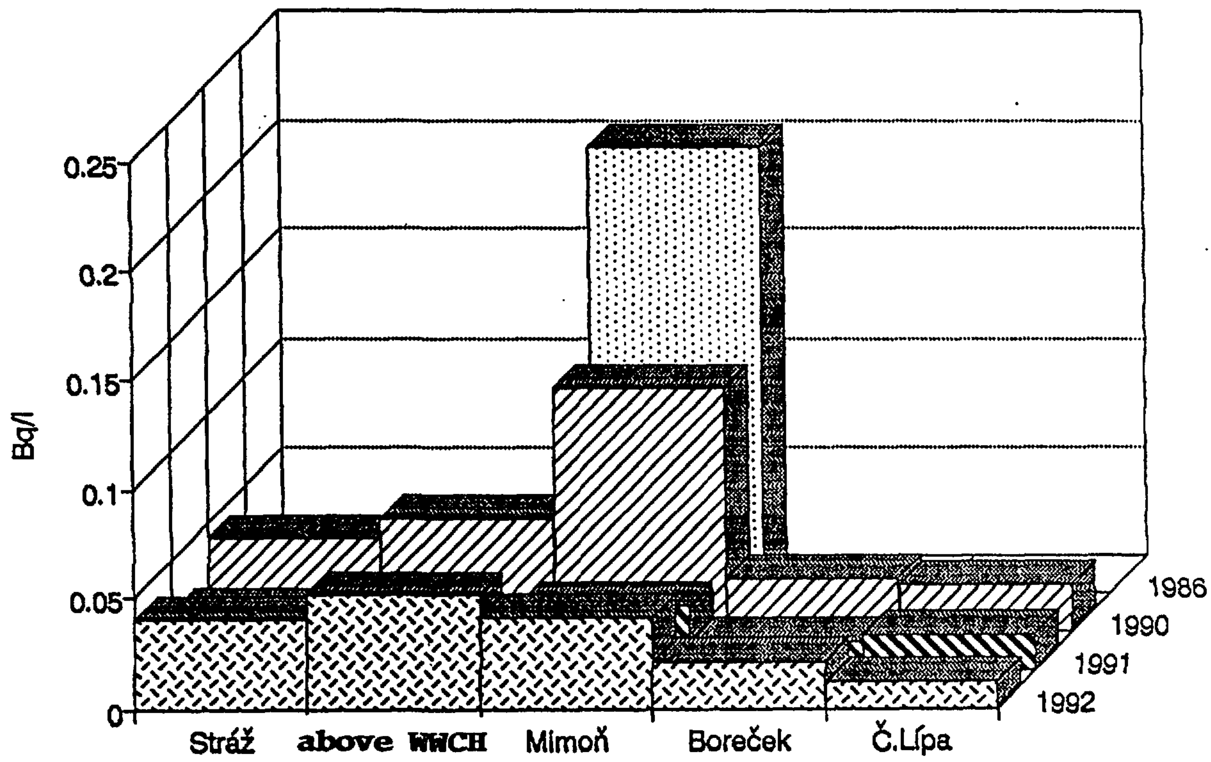


FIG. 7. a) Experimental floods; radium-226 concentration, dissolved substances, maximum value.



b) Experimental floods; radium-226 concentration, suspended particles, maximum value.

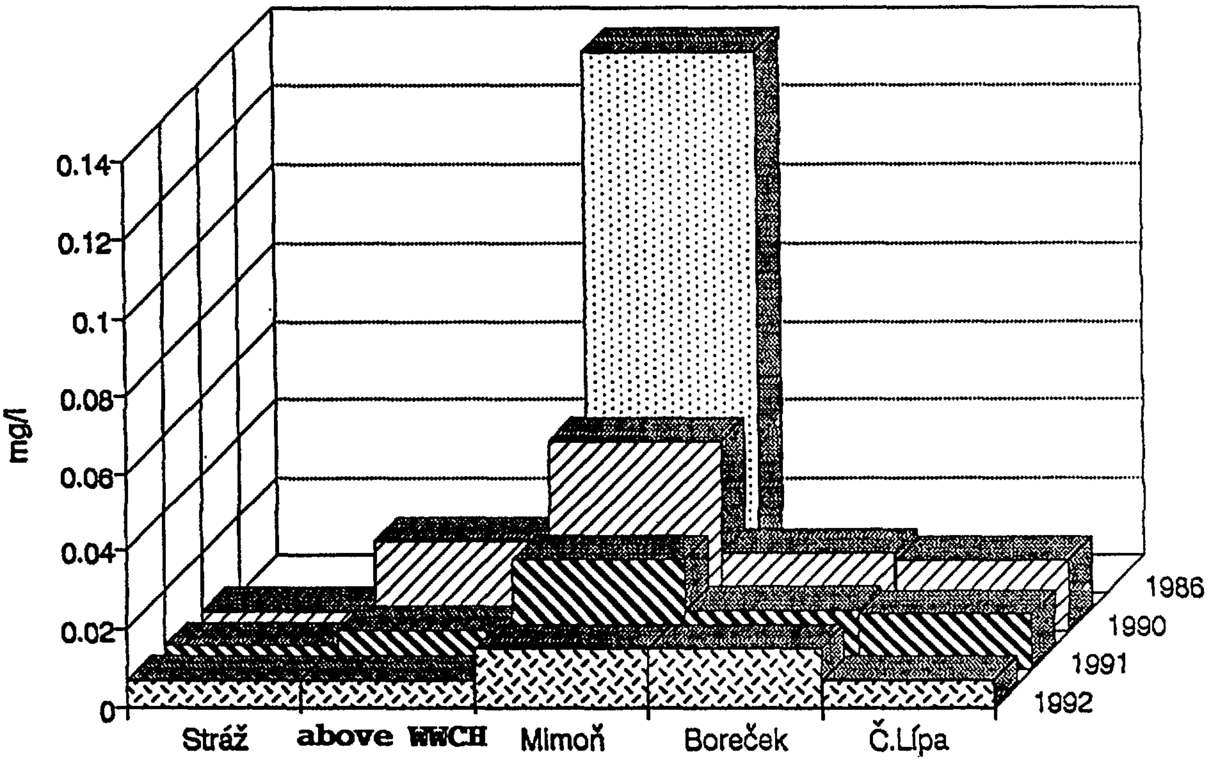
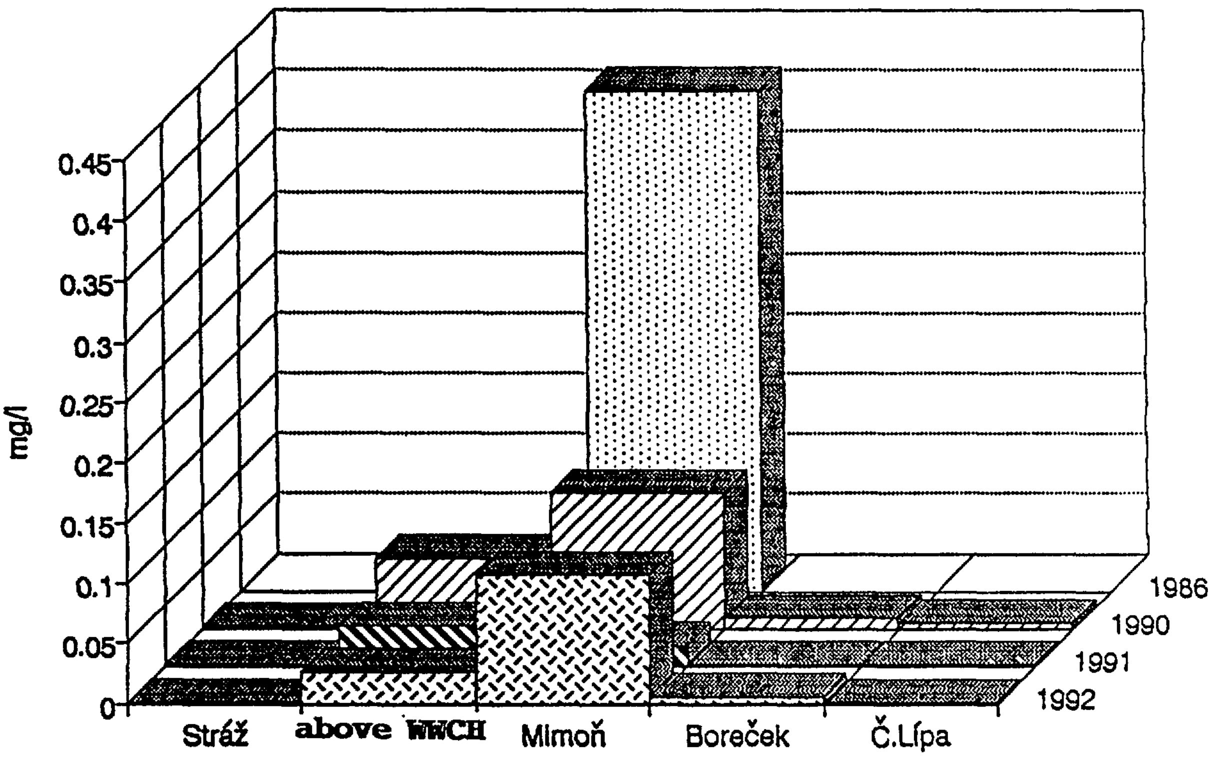


FIG. 8. a) Uranium-238 concentration, dissolved substances, maximum value.



b) Uranium-238 concentration, suspended particles, maximum value.

background-level monitoring locality of the Ještědka River and in sediments collected from the Ploučnice River downstream of the Mimoň locality. The results show that the concentrations of radium-226 and uranium-238 in interstitial water, collected at the affected reaches of the Ploučnice River, correspond to the content of these radionuclides in dissolved form in the Ploučnice River prior the operation of the Central Decontamination Station. Based on the knowledge concerning transport of radioactive substances by the Ploučnice River and with respect to the results of the budget assessment discussed above, it can be concluded that changes of the radioactive substances content in the bottom sediments are significantly delayed in comparison with the change (improvement) of water quality after putting the CDS into operation in 1989.

Ratio of the radium-226 and radium-228 given in Fig. 6 is a good indicative value for impact assessment of waste products of uranium mining industry on contamination of bottom sediments or soils in flood plains of the Ploučnice River. The average value of the ratio for loaded reaches of the Ploučnice River is 32 and for its tributaries free of uranium mining industry activities it is less than 2.6.

2.3. Transport of radioactive substances during experimental floods

In the period 1986-1992, the transport of radioactive substances during high flows in the Ploučnice River was tested experimentally by making artificial floods using water stored in the Horka reservoir situated at the Stráž pod Ralskem municipality (see Fig. 1).

Content of radium-226 and uranium-238 in both suspended and dissolved form was analyzed using water samples collected at the water streamline in 1/3 of the depth below water surface. The samples were collected from the Ploučnice River downstream of the Horka reservoir situated in the Stráž pod Ralskem municipality, upstream of the waste water outlet, upstream of the Mimoň locality, in the Boreček locality and in the Česká Lípa municipality.

Examples of graphical representation of the maximum radium-226 and uranium-238 concentrations in dissolved substances and suspended particles are given in Figs 7 and 8. The values, observed in 1986, correspond to the Ploučnice River contamination before operation of the Central Decontamination Station. The values from 1990, 1991 and 1992 are in agreement with the lower load of the Ploučnice River after putting the CDS into operation, but also with decontamination effect of high water discharges during experimental floods and higher natural discharges in the observed reaches of the Ploučnice River. Examples of variations of the radium-226 volume activity in time in suspended and dissolved matter are given in the Figs 9 and 10 for sampling points of the Mimoň and Česká Lípa respectively. It is obvious from the graphical representation that the radium-226 concentration was decreasing in both of the forms and that the wave of the pollutant runoff was smoothing. It decreases much more rapidly in comparison with the discharge of water. Table III presents results of the budget assessment of the radium-226 and uranium-238 for particular experimental flood waves in the relevant sampling points. It follows from the results, that the highest decrease of the amount of transported radioactive substances, particularly of their suspended form, caused by sedimentation in the river channel and mainly in the flood plain, occurs in the Ploučnice River reaches where the highest specific radium-226 concentrations in bottom sediments were measured.

The results of measuring of transport of radioactive and non-radioactive substances during experimental flood in 1992 were used for calibration and verification of the MIKE 11 and MIKE 21 mathematical models and for the model simulations performed in cooperation of several institutions — the Ohře River Water Authority, the T. G. Masaryk Water Research Institute in Prague, the Technical University in Prague, the Hydroinform, the Hydrosoft, the Danish Hydraulic Institute and the Water Quality Institute (Denmark). This was done within the Pilot Study of a project prepared in the framework of the Methodology for Revitalization of the Ploučnice River System in 1992. At present, the computation of transport of radioactive substances is being completed [9].

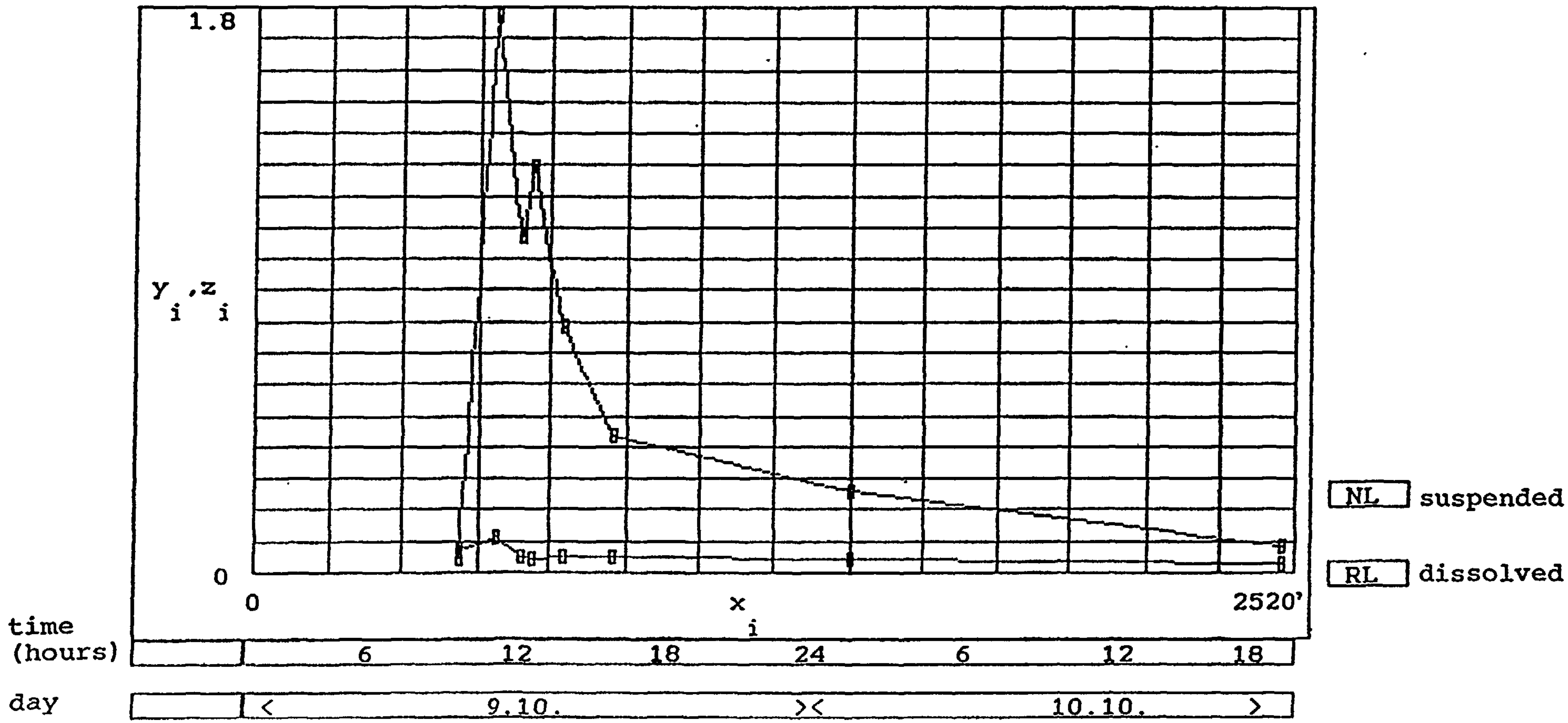


FIG. 9. Volume activity of radium-226 in suspended and dissolved matter (Bq/l), sampling point Ploučnice-Mimoň, experimental flood of 9/10/1990.

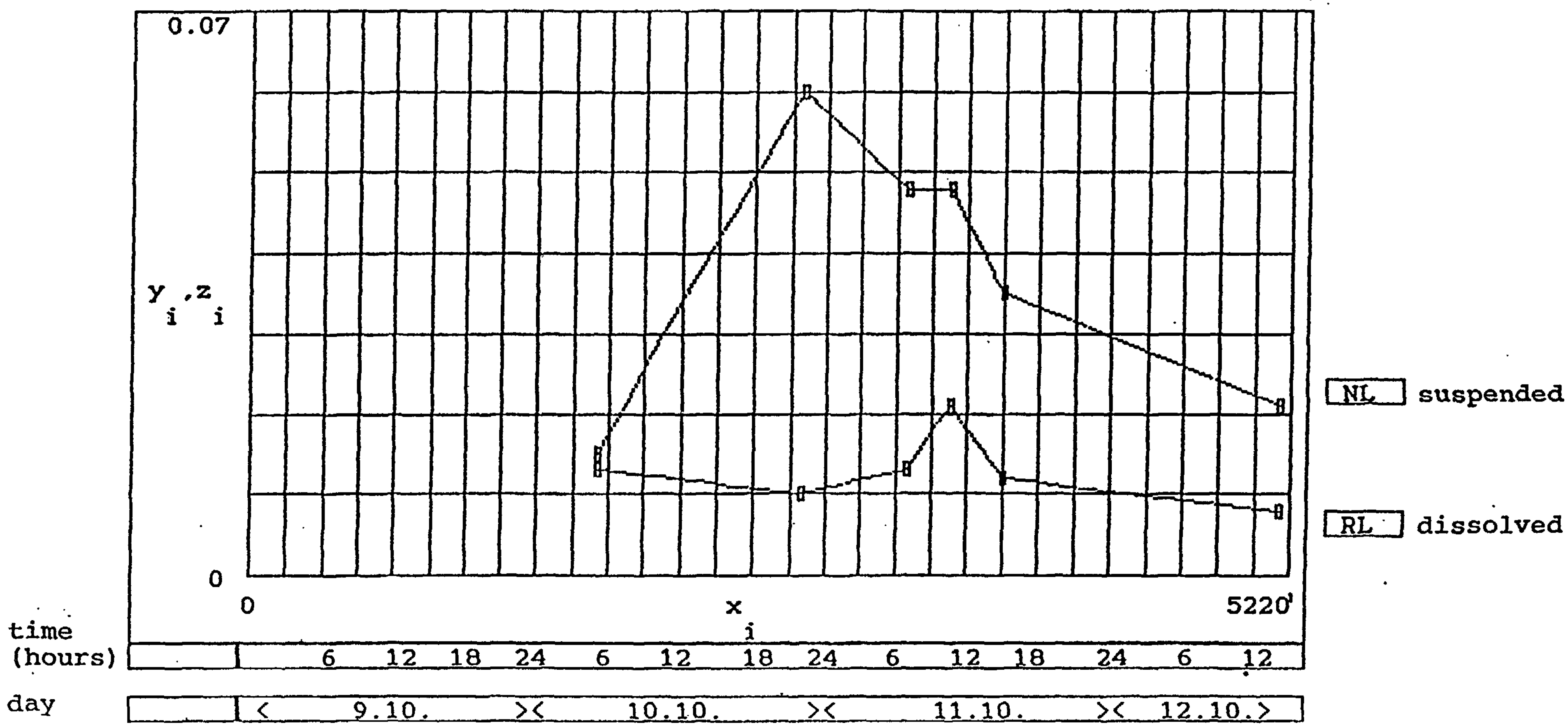


FIG. 10 Volume activity of radium-226 in suspended and dissolved matter (Bq/l), sampling point Ploučnice-Česká Lípa, experimental flood of 9/10/1990.

TABLE III. RUNOFF OF RADIOACTIVE SUBSTANCES DURING EXPERIMENTAL FLOODS IN 1986, 1990, 1991 AND 1992.

Year Sampling point	Ra-RL	Ra-NL	U-RL	U-NL
	MBq	MBq	kg	kg
1986				
Mimoň	10.68	264.10	1.57	15.03
pit water x)	0.127	2.153	0.179	0.216
1990				
upstream of channel	5.84	29.99	0.51	2.00
Mimoň	12.36	202.10	9.49	12.89
Boreček	12.50	37.61	8.96	2.81
Česká Lípa	7.88	37.17	11.06	1.94
pit water x)	0.578	0.644	0.067	0.023
1991				
upstream of channel	3.43	12.59	1.73	1.00
Mimoň	10.59	86.64	4.97	1.08
Boreček	4.89	22.67	5.42	0.82
Česká Lípa	10.09	15.77	9.57	1.60
pit water x)	0.022	0.040	0.076	0.007
1992				
upstream of channel	7.07	24.36	1.52	0.62
Mimoň	10.41	86.94	4.11	4.86
Boreček	9.49	26.80	5.67	1.13
Česká Lípa	9.54	24.44	5.30	1.06
Děčín	13.24	21.99	13.52	1.99
pit water x)	0.023	0.061	0.030	0.007

x) Mean hourly amount of radioactive substances in pit water outflow from diversion channel (MBq/h, kg/h)

2.4. Flood plain contamination

Observation of the transport of radioactive substances under higher discharges helped to explain the mechanism of the Ploučnice River flood plains contamination obtained by ground and aerial measurements of gamma radiation intensities [10, 11]. For assessment of changes of the gamma radiation intensity as a consequence of covering the soil by sediments with lower specific content of radioactive substances and of the migration of radionuclides into greater depth, a control system was developed in selected cross sections of the Ploučnice River flood plains. Fig. 11 presents an example of results of a field measurement in the Boreček site with the cross-section of 186 m width. Results of measurements from the period 1992-1994 indicate slow decrease of the of gamma radiation intensity. The background gamma radiation ranges between 15 and 35 $pGy.s^{-1}$ in the area under the study.

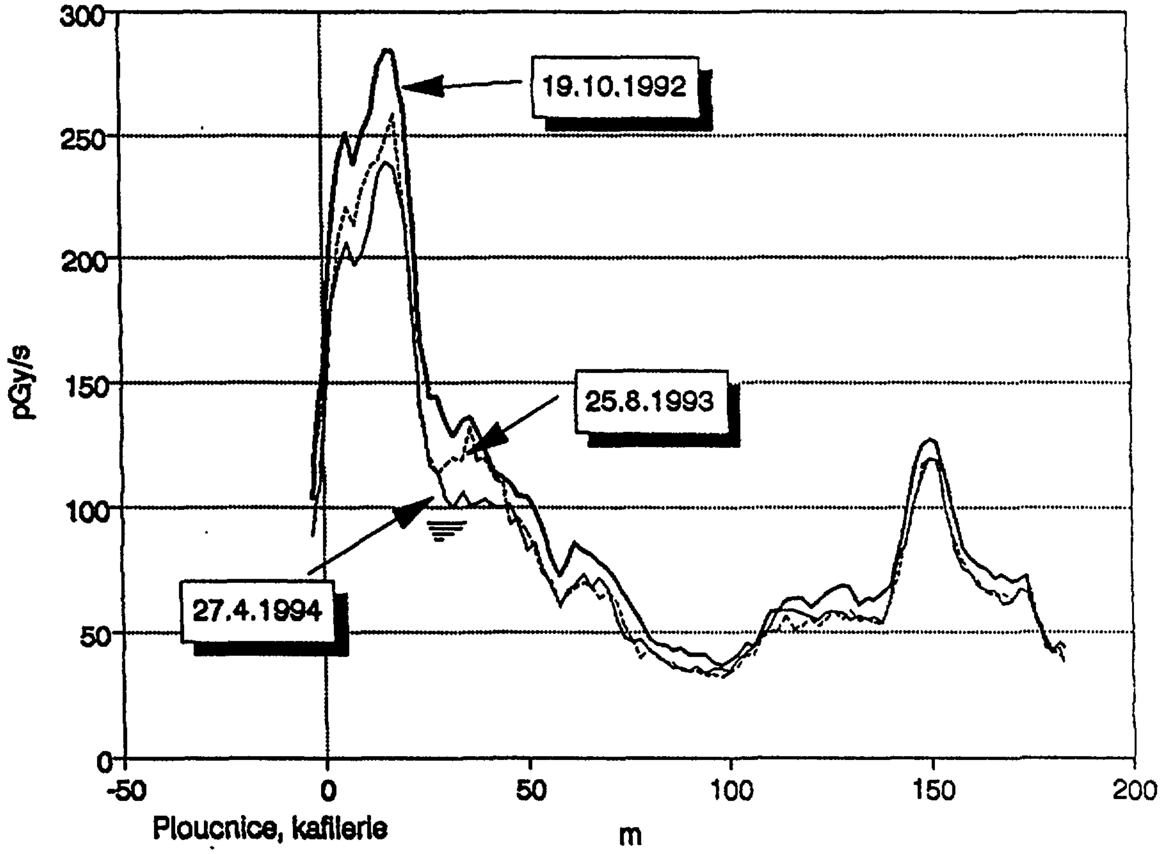


FIG. 11. Gamma radiation in flood plain at a distance of 15 km from the waste water outlet (Boreček).

3. SUMMARY

The paper summarizes selected results of the detail observation of the impact of mining and processing of uranium in the North Bohemia region around the Stráž pod Ralskem municipality on the Ploučnice Basin contamination by radioactive substances in the period 1986-1994. During this period, waste water from uranium mining industry had first been treated by provisional water treatment plant and since 1989 by the effective treatment by the Central Decontamination Station.

Significant improvement of water quality with respect to radioactive substances in both dissolved and suspended form was detected after putting the Central Decontamination Station into operation in 1989. The Ploučnice River water quality comply, in radioactive indexes, with requirements specified by the Annex III of the Czech Government Decree No.171/1992 Stat.

The improvement of water quality together with data on contamination of bottom sediments and flood plains by radioactive substances demonstrate also outlasting of secondary sources of contamination in the basin and practically neglectful decontamination (self-purification) by overland washing and desorption of bottom sediments. This fact is documented by measuring of radioactive substances content in bottom sediments of the Ploučnice River downstream of the waste water outlet. Previously measured contents, particularly of radium-226, have not changed and the highest specific activities have been identified in the area of the so-called central deposits of secondary contamination situated between the Mimoň and Česká Lípa municipalities.

Insignificant trends of sediment contamination by radioactive substances have been identified in vertical samples of more deeply deposited bottom sediments. Lower concentration was only observed in the surface layers of sediments. This fact is in good conformity with the data on insignificant increased loads of radioactive substances in the Ploučnice River after beginning of operation of the Central Decontamination Station. Radiometric analysis of particular granularity fractions of the Ploučnice River sediments showed that the highest mass concentrations are in clay fraction with the grain sizes less than 0.08 mm.

The observation of the transport of radioactive substances during the experimental floods demonstrated their deposition in suspended form in the central deposits situated between the Mimoň and Česká Lípa municipalities. Observation of radioactive substances in water, in suspended particles, in interstitial water and in bottom sediments was used for model simulation of transport of radioactive substances in the basin.

For monitoring of changes of flood plains contamination by radioactive substances, the system observing gamma radiation intensity was built for permanently observed cross-sections. No significant trends in measured intensities have been detected until now.

At present, places with the highest content of radioactive substances are detected as a basis for decision-making concerning plans on their decontamination.

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UTILIZATION OF AVAILABLE EXPERIMENTAL DATA FOR POLLUTANT TRANSPORT EQUATION COEFFICIENTS AND SOURCE TERM CORRECTION

(Abstract)

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Physical equations describe always a certain circle of processes the validity of which should be verified by a subset of validity and the sense of their applicability lies in a capability to forecast and predict situations which we do not know at all or know partially and approximately only and therefore we want to have a more precise description at our disposal. For example, the equations describing transport of pollutants in an unsaturated water zone depend on a knowledge of a series of data which have their origin in a set of physical and/or chemical branches. The common current procedure represents a comparison of calculational results with those of measurements and, in case significant discrepancies are detected and the disagreement is not accepted, a revision of the theory is necessary and the whole time and effort consuming process (starting from basic soil parameters and chemical processes involved in the pollution mechanism and its sources up to the solution of time dependent equations) has to be repeated. In addition, the question of which part of the calculational procedure has a maximum share in the discrepancy used to be a very difficult one and not unique to be simply answered. There is an alternative procedure described in the paper which is based on a direct incorporation and experimental results into the basic equation and so the correction of its coefficients. This new model, where the experiments are not only used for its verification or contradiction but also for a broadening of information base of its creation as well as more accurate data on chemical reactions, soil properties and mutual interactions of the processes involved, is mathematically described as a minimization of a functional formed by a sum of the squares of differences between computational and experimental values divided by the values of measuring errors with a side condition of a fulfilling of a set of partial differential equations forming (according to the nature of the task) either an eigenvalue or a non-linear and time-dependent problem. There is a principal mathematical algorithm allowing an optimal elaboration of all the data involved in the process (streaming of unsaturated water with pollutants generated in the process of uranium mining in the subsurface layers of the earth crust and during the uranium mine and mill closure) with a condition of the most precise prediction of the future situation presented in the paper.

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