FINAL FEASIBILITY STUDY OF POSSIBILITIES AND POTENTIALS OF THE DISUSED IRON ORE MINE KONRAD (FGR) FOR LOW-LEVEL WASTE AND DECOMMISSIONING WASTE DISPOSAL

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INTRODUCTION

The "Institut für Tieflagerung" of the Gesellschaft für Strahlen- und Umweltforschung, in collaboration with the Kernforschungszentrum Karlsruhe, carries out geoscientific and technical investigations in the disused iron ore mine Konrad. The aim is to prove the mine's feasibility for the disposal of low-level radioactive waste and decommissioning waste as well as the use of the existing mining installations. The investigations were initiated in 1975 and are being financed by the Minister for Research and Technology of the Federal Republic of Germany. Since 1978 the work is being supported as well by the Commission of the European Community in the scope of two years each. So far an amount of 60 mio DM has been spent, 86 % for maintenance and further operation of the mine and 14 % for research work.

The latest status report on the feasibility study was published in December 1980 stating already positive results with respect to the geology, hydrogeology, rock mechanics and the technical use of the mine. The extensive R & D-programme was finished at the end of 1981 and a final report is going to be published mid 1982 giving in detail all investigation results.

The report features, in particular,
- a comprehensive site description,
- the properties of the geological barrier,
- specific hydrogeological aspects of the future waste repository for both the operational and post-operational stages,
- rock mechanical aspects for the excavation of safe cavities in the iron ore formation,
- a full description of all existing mining installations and mining equipment as well as a technical evaluation of their use for a future disposal operation,

- a description of all waste categories to be disposed off in the repository and the respective waste mass accumulation in the Federal Republic of Germany,
- the mining and technical concepts for the construction and the operation of the waste repository including an efficiency analysis,
- a safety assessment for the regular disposal operation and for specific fault events as well as
- shut down concepts for the post operational stage.

During the forthcoming years the R & D-programme will be continued in the Konrad mine with basic research work on the use of non-saline hard rock for all categories of radioactive waste disposal and the development of advanced investigation methodologies.

However, on the basis of the results achieved so far, a licensing procedure is planed to be initiated in 1982 for the disposal of low-level waste and decommissioning waste. This is the outcome of a discussion at the ministry level between the Federal Government and the State Government of Lower Saxony which was held on the subject of low level waste disposal in September 1981.

The licensing procedure for construction and operation of a final radioactive waste repository in Germany is dictated by paragraph 9b of the German Atomic Law. In accordance with this law, application for a license has to be made by the Physikalisch-Technische-Bundesanstalt on behalf of the Federal German Government. The regulatory body is the State Government of Lower Saxony. Apart from licensing under the Atomic Law a mining license has to be granted for the underground waste repository by the appropriate mining authorities.

It is expected that licensing will take about four years before a final decision on the future utilization of the Konrad mine as a radioactive waste repository has been reached. Thereafter the necessary alterations to the plant and the excavation of underground disposal rooms can be done, which will take another 2 - 3 years. So a final waste repository will be put in operation in 1989 at the earliest.

SITE DATA AND HISTORY OF THE MINE

The iron ore mine Konrad is located in the outskirts of the city of Salzgitter, a traditional mining center in the eastern part of Lower Saxony. The mine is close to the steelworks of Peine-Salzgitter AG which employs a labour force of about 15.000. The surface installations at production shaft Konrad 1 are connected by a feeding road with a near-by motor freeway. A railhead and access to a waterway with harbour facilities are also available.

The iron ore formation was deposited 150 million years ago as marine sediments in an alternating sequence with limestones, marlstones and claystones of the Upper Oxfordium (Jurassic). Today it is found at great depth only under a complete cover of cretaceous formations and as part of the "Gifhorner Trough". This geological structure strikes generally north to south over a distance of 60 km. It is up to 15 km wide and covers an area of about 500 km^2. The total estimated ore reserves amount to 2 billion tons. The Konrad mine has been established at the southern rim of the trough after an extensive drilling and exploration programme had proved good ore qualities and ore reserves of about 50 to 60 mio tons for this location. The thickness of the iron ore formation varies between 12 m and 18 m and dips gently at 20° in a westerly direction. The iron content avarages 31 to 33 wt % Fe. The silica makes up 15 wt % of which approx. 10 wt % is free silica and calcium oxide reaches 15 wt % as well. The oolithic iron ore being comparable to the Minette-Type consists mainly of ooides which are formed by goethite and chamosite and some matrix material.

In 1960 the main shaft Konrad 1 was sunk down to its final depth of 1232 m. In late 1962 the ventilation shaft Konrad 2 was completed to 999 m depth. The shafts are placed 1.5 km from each other. They were connected by the 1000 m-mining level in January 1963. Subsequently two more levels were developed at 1100 m and 1200 m below surface. For exploitation, two different mining methods were employed. Initially the ore was mined by blasting and scraping in big chambers which were later backfilled. By the introduction of diesel driven engines underground and the loading-hauling-dumping system, a room and pillar mining method using the technique of pillar carving was applied. Until 1976 a total cavity volume of 2.5 mio m^3 was opened for exploitation and 6.6 mio tons of ore were hauled. Despite the close distance to the ore smelters the ore became more and more non-competitive with the imported iron ores. The production was finally terminated in fall 1976. At this time preliminary investigations for use as a radioactive waste repository had already begun.

RESEARCH AND DEVELOPMENT PROGRAMME

The preliminary site investigations were started in 1975. The main task was to check on the most crucial criteria applicable for radioactive waste repositories in order to identify the main assets of the mine and to establish a catalogue of scientific and technical R & D-work to be performed as a part of a feasibility study. Already at this early stage there were strong indications that no major disadvantages exist which could hamper the safety of a waste repository in the mine. Here the extensive knowledge of the mine's geology and hydrogeology gained by ore exploitation and 20 years of mining experience was extremly valuable leaving very little to do for additional site investigations. As a matter of fact not only the geology but also the technical installations seemed to be suitable for waste disposal operations. In view of the waste categories considered, an extensive investigation programme was set up. Among others, the following investigations have been carried out:

A. Earth Science Investigations

A. 1 Petrology

- measurement of grain size distribution and specific grain surface areas of various rock types such as iron ore and sandy to marly claystones in company with sorption tests,
- measurement of porosity, permeability and distribution of pore radii at representative rock samples, particularly of more porous rock types,
- qualitative and semi-qualitative determination of the mineral composition and specifically the content of smectites in claystones of the barrier formation by x-ray diffraction,
- determination of claystone structures and intergrowth texture of clay minerals by electron-microscope-scanning,
- determination of water adsorption and swelling properties of claystones by an Enslin apparatus,
- determination of volume changes of claystones on heating by dilatometer measurements,
- determination of cation exchange capacities of various rock types for cations corresponding with the waste inventory,
- determination of distribution coefficients (k_d-values) for various rock types and backfilling material using batch tests,
- determination of the diffusion coefficients for the main rock types of selected radionuclides.

A. 2 Hydrogeology

- characterization of aquifers according to hydrogeological standards,
- continuous measurements of groundwater level in an area affected by surface depression as a result of previous mining activities,
- monitoring of the mine's water balance with registration of water consumption underground, seepage water in the mine, water discharge and ventilation air humidity,
- determination of residual formation water and its movement through the rock mass by a large scale ventilation test,
- in situ-permeability tests in sections of disintegrated rock mass around mining galleries by hydraulic pressure tests in boreholes.

A. 3 Geochemistry

- chemical and physical supervision of the mine's seepage water in regular intervals by chemical analysis and pH and bulk density measurements,
- characterization of the iron ore formation water by specific trace element studies and comparison with the water chemistry of neighbouring rock strata,
- equilibrium calculations for the pore water of the different water bearing formations by the use of the WATEQ computer programme,
- determination of S-34, S-32 and H-3 isotopes in the mine water for age dating and proof of non-existence of water pathways between mining levels and near surface aquifers,

- determination of trace elements and S-isotopes in secondary mineralized salt crusts at rock faces and along fracture zones.

A. 4 Tectonics

- detailed tectonical mapping and statistical evaluation of direction, size, opening, secondary minerals, affected rock strata and location of faults, fractures and fissures by the computer programme GELI,
- determination of the condition of rock fractures and fissures by tv-logging in boreholes and their behaviour under increased deformation stress caused by mining.

A. 5 Rock Mechanics

- deformation measurements in existing cavities with different sizes and profiles for determination of convergence rates in relation to mine development,
- in situ-stress measurements by bi- and tri-axial cells, dilatometerprobes and hydraulic fracturing tests,
- stress and tension measurements of different rock types as well as shear strength tests at selected tectonical and bedding planes in the iron ore formation by laboratory methods,
- calculations of the rock mechanical stability of mined cavities in the iron ore formation and prediction of future convergence and surface depression for a proposed repository concept.

A. 6 Geophysics

- continuous registration of seismicity at site,
- identification of secondary seismic events in the mine by an array for high frequency seismic signals,
- determination of Young's and shear moduli in different parts of the mine by artificially generated waves,
- tiltmeter measurements for evidence of neotectonical movements along the main tectonical joints,
- geoelectrical measurements for the detection of water pathways in the mine,
- ultrasonic measurements in boreholes for the determination of rock disintegration in pillars between mining galleries.

B. Mining Investigations and Repository Concept

- development of concepts for the alteration of existing mining installations with consideration of the technical requirements for radioactive waste disposal,
- proof of the usefulness of existing machinery for future mining and disposal operation,
- development and testing of mining concepts for future disposal cavities including the feasibility of latest mining techniques,
- calculation of the disposal capacity of the future repository and development of a preliminary flow chart for ore production and waste transport,
- development of a ventilation concept providing for separate mine ventilation in development and disposal sections,

- development of concepts for mine drainage and sewage surveillance,
- development of backfilling concepts for disposal cavities and shafts,
- provisional cost analysis for construction and operation of the repository.

C. Nuclear Engineering Investigations and Radiation Protection Concepts

- description of waste categories, waste masses, waste transport and delivery relevant to a repository "Konrad",
- conceptual design of the repository's installations and its construction with respect to the requirements of nuclear technology,
- development of disposal techniques for LLW in drums and decommissioning waste in containers e. g. 10 ft-containers,
- development of a radiation protection concept for receipt, handling, internal transport and waste emplacement,
- safety analysis for selected fault events during operation of the repository,
- development of a shut down concept for the repository,
- safety assessment fo the post-operational phase.

It has to be stated that the investigation programme was influenced by the specific situation of the Konrad mine, especially the high level of previous geological exploration, and the safety requirements set by the waste categories to be disposed of. In addition some of the investigations were stimulated by the experience gained in the Asse salt mine, the pilot repository for LLW and ILW in the Federal Republic of Germany. For any other repository a different research programme might be desirable to collect the information needed for a comprehensive feasibility study. According to our knowledge and experience, the scope, quality and results of all investigations contained in the final report are sufficient to prove the feasibility of the Konrad mine as a LLW-repository, but additional investigations might be requested by the regulatory body during the licensing procedure.

SITE SPECIFIC POSSIBILITIES FOR WASTE DISPOSAL

The site specific possibilities for the disposal of LLW and decommissioning waste derived from the geological, hydrogeological and rock-mechanical investigations can be indicated as follows:

- great and secluded depth of the ore deposit (800 m - 1200 m below surface) without any outcrops, near surface workings and contact to near surface workings,
- the lack of large water-bearing rock formations in most of the covering strata and particularly in the neighbouring rock mass of the mine workings,
- the existence of extensive impermeable claystone formations in the covering rock strata (800 m - 1000 m in thickness) partly composed of clay minerals with considerable swelling and sorption properties. These claystone formations are the actual geological barrier of the final repository forming a water seal even for long-lived radionuclides.

- the rock mechanical properties which permit the development of suitable disposal cavities for the application of safe and efficient disposal techniques,
- the location of the mine in an area of low seismicity.

In addition, it must be stated that, as a result of the described particular geological site situation, the mine is extremly dry. For this reason water, needed for mining purposes such as drilling and dust fighting must be pumped underground. Limited water intrusions have been experienced in the past when cutting through fault zones which occasionally contained pressurized and highly mineralized water. In each case, the water flow exhausted after a short time and has stayed dry since then. At other spots within the mine even open rock fractures were found which were completely dry. Today only 5 l/min are being collected at pumping stations in the entire mine, except at ventilation shaft Konrad 2. This amount includes the water being used in the mine. The residual moisture content of the iron ore formation is extremly small, appearing only here and there as seepage water. According to geochemical comparison the mine water does not correspond with meteoric water and its age seems to be millions of years. To date, mining activities have not changed this exceptionally favourable hydrogeological situation. Therefore nuclid migration from the repository into the biosphere via water pathways, even over extended periods of time, seems to be most unlikely for the simple reason that such pathways just do not exist. This leaves only the two shafts which have to be sealed off properly when closing down the repository.

TECHNICAL POSSIBILITIES FOR WASTE DISPOSAL

From the technical point of view it must be established that the installations of the production shaft are still modern and adequate to todays standards of mining technique. This applies especially to the shaft and the hoisting equipment. Hoisting engine, head frame and cage were originally designed for loads of 20 tons net and they can be adjusted to this hoisting weight after some minor alterations. The shaft of 7 m diameter is suitable for the use of a large cage with a bottom plate of 2,4 m x 2,4 m and a height up to 6 m for the haulage of the waste casks. On the underground roadways of the 1000 m-, 1100 m-, 1200 m-level and sublevels, diesel engine-driven transport vehicles and loading trucks with up to 20 tons of load can be used.

The technical advantage of the mine with respect to mining engineering are as follows:
- Cavities to be excavated in the iron ore are mechanically stable. Due to a proved method of roof bolting the convergence rate in the mine cavities can be kept at a very low level, which guarantees operational safety even for long periods of time.
- Technical alterations in the mine necessary for waste disposal can be carried out at relatively low cost. Main consideration has to be given particularly to the buildings at the main shaft where an entrance hall for the waste casks has to be errected.

In addition a special cage for waste transport in the shaft and an off-loading station at the 1100 m-level have to be constructed in order to derive as much benefit as possible from the large shaft diameter with respect to hoisting capacity.
- The lay-out of the mine allows the development of up to 1 mio m^3 cavity volume underground. At present only haulage ways on the three main levels and an interconnecting ramp exist, but disposal rooms can be mined at any time after licensing, either before or simultaneously with the waste disposal operation. The iron ore resulting from this sort of mining can be used as backfill material or sold to the nearby steelworks. For this reason a mine dump does not have to be considered.

The final waste disposal concept for the Konrad mine was developed specifically with a view towards the disposal of low level and decommissioning, non heat-generating wastes delivered in a conditioned form and packed in drums and containers. The feasibility investigations refer exclusively to these categories of waste and thereto how these wastes can be transported underground safely and economically for disposal. Up to now other types of radioactive waste were not considered in agreement with the task set by the Ministry of Research and Technology.

WASTES SUITABLE FOR FINAL DISPOSAL

In the Federal Republic of Germany the quantity of low level waste piling up since the pilot repository Asse was closed at the end of 1978 provides an increasing problem, which is presently solved by interim storage. These wastes are mainly activated or contaminated solid wastes and solidified wastes from nuclear power plants as well as wastes from nuclear research centers, hospitals and industry. By the end of 1980 LLW in about 23.400 units of 200 l-drums, 3.500 units of 400 l-drums and 8.300 units of 200 l-drums with concrete shielding had accumulated in several storage facilities of the various Federal States in the FRG. It is estimated that in the year 2000 the annual amount of LLW will range from 14.500 to 30.000 units of 400 l-drums, depending on the number of nuclear power plants put into operation and the conditioning technique being used. For the development of a disposal concept as well as for the safety assessment for the Konrad repository it was assumed, that these wastes are packed in 400 l-drums only. Waste activity and waste conditioning comply with the latest Asse acceptance regulations since no other regulations are enforced yet by the licensing authorities. This includes in general the radiation dose limitation of 200 mrem/h at the surface of the waste cask and 10 mrem/h at a distance of 1 m.

Additional waste of this category but of lower specific activity is expected from the decommisioning of nuclear power plants after the year 2000. Presuming the operating time of each unit is as long as 30 years, the first twelve nuclear power plants put into operation in the FRG are then due to shut down between 1996 and 2009. If decommissioning starts one year after shut down the waste masses resulting from these 12 power plants amount to approximately

85.000 tons of which 80.000 tons are LLW. This amount of waste makes up about 67.000 m³ of waste volume. Using the Konrad mine as a repository, 10 ft-transport containers will be acceptable as waste casks. The maximum gross weight of 20 tons is limited by the capacity of the hoisting equipment.

The radiation exposure of the working personnel, particularly due to waste handling and underground transport, has been calculated on the basis of the experience gained in the pilot repository Asse. The results have proved that normal disposal operations in the Konrad mine involving the above waste categories and waste casks can be done without exceeding the limit values for operating personnel laid down in the national German radiation protection regulations. The use of pallets for transporting waste drums and special manipulating devices for loading and stacking of waste casks will help to reduce radiation doses even with increasing disposal operations.

The long term safety of the repository has been calculated by a transport model for the most important radionuclides which was based on the geological and hydrogeological features of the site as well as on the half lives of these radionuclides. Based on the half lives of Co-58, Co-60 and Cs-134 the main proportion of the waste inventory decays in less than 200 years. Within 1000 years, nuclides such as Cs-137 and Sr-90 decay below a billionth of their initial activity. Due to the efficiency of the geological barrier, particularly of the large claystone formations, these wastes will be detained for even longer periods of time within the repository enabling even the longer lived radionuclides to decay far below non hazardous levels while separated from the biosphere.

DISPOSAL POTENTIAL OF THE REPOSITORY

Taking into account mining and nuclear engineering safety requirements a disposal model based on a system of horizontal and parallel mine galleries seems to be the most favourable in the Konrad mine. Such disposal galleries may reach a cross sectional area of 40 m² and an extension of some 100 m separated by safety pillars of about 40 m to 50 m width (Fig. 1). This guarantees an ecconomic use of the iron ore formation in consideration of rock mechanical safety aspects. Additional advantages related to the size, shape and configuration of the disposal galleries can be stated as follows:

- use of tunneling machines such as a continuous rock miner for a reduction in the number of development workings without loss of efficiency, for limiting rock mechanical movements and for maintaining a most favourable gallery profile,
- short distances for iron ore hauling and waste transport with sufficient space for movement of diesel engine-driven vehicles,
- good stowing capacity by stacking of waste drums and containers,
- simple and efficient mine ventilation with separate ducts for development and disposal areas in the repository.

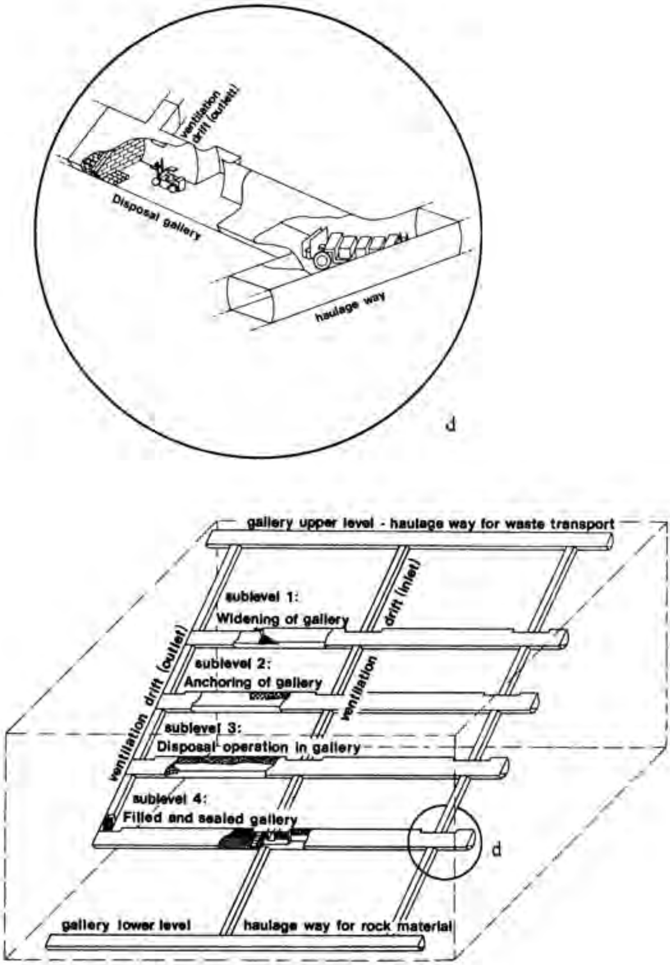

Fig. 1. Development of mine galleries for the disposal of LAW-drums, (d) Designer's view of the disposal operation in mine galleries (W, Brewitz, G. Gommlich & K. Rabsilber, 1980).

In the first stage of construction it is possible to develop mine galleries for the first disposal of about 128.000 m³ of waste in the southern parts of the mine field.

After alteration of the hoisting equipment it will be possible to dispose annually 12.500 m³ of waste in the repository based on a single shift operation with simultaneous ore production. This quantity matches the calculated annual LLW production in the Federal Republic of Germany. By such an operation the total cavity volume to be developed in the Konrad mine will last for approximately 40 years. In principle, the doubling of the disposal performance is possible by a two-shift operation, shortening the life of the repository accordingly.

Nevertheless, it has to be stressed that, in spite of the large hoisting capacity of the mine, it is not possible to increase the disposal capacity to a level needed to deal efficiently with the LLW-masses that will have accumulated in the Federal Republic of Germany before the repository has been put into operation. This is valid under the assumption that, except for some old mine galleries which can be used after reworking and anchoring the hanging wall, disposal cavities will be permitted to be driven only after successful licensing. As the operating license for Konrad is not being expected before 1989 the accumulated amount of LLW in the FRG requires another repository for final disposal. Under present aspects this might be the former pilot repository in the Asse salt mine as well as the repository at Gorleben which is being investigated for its feasibility as a repository at present.

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