UPGRADING OF THE MOCHOVCE NATIONAL RADWASTE REPOSITORY DURING ITS COMPLETION

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ABSTRACT

The National Radwaste Repository Mochovce is a disposal facility of surface type. It has been designed to dispose ultimately treated and conditioned low- and medium-level radwaste, generated during the operation of nuclear installations on Slovak territory, as well as radwaste produced in the course of various activities in research institutions, laboratories, hospitals, and other institutions – the so-called institutional waste. The operator of the repository is the Bohunice-based affiliation of the SE utility – Decommissioning of Nuclear Power Installations, Management of Radwaste and Spent Fuel (SE-VYZ). During completion of the repository, a number of enhancements were implemented as recommended by an IAEA WATRP mission (Waste Management and Technical Review Program) and requested by the Nuclear Regulatory Authority of the Slovak Republic (UJD SR) with the objective to upgrade safety of the repository.

INTRODUCTION

The National Radwaste Repository for Slovakia in Mochovce (repository) was commissioned at the end of 1999. During the completion of its construction in the period 1997 to 1999, a number of enhancements were implemented as designed based on the requirements of the regulatory body from 1995. These requirements resulted from the conclusions of an international audit organized in cooperation with the Vienna-based International Atomic Energy Agency (IAEA). The requirements were related mainly to performance improvement of drainage system, prevention of rainwater infiltration into disposal spaces in the course of disposing, and strengthening of slope stability. The operator of the repository is the Bohunice-based affiliation of the SE utility – Decommissioning of Nuclear Power Installations, Management of Radwaste and Spent Fuel (SE-VYZ).

The performance improvement of the drainage system was implemented by building a completely new drainage system that makes it possible to control the presence, sampling, and removal of possible water from individual disposal boxes. In line with the original concepts, it also makes possible to remove water from the drainage layer of gravel sand below the disposal boxes at the bottom of the clay bath, and to remove water infiltrated via the system of controlled water drainage from the external perimeter of the clay bath. The clay bath provides the basic barrier separating the disposed radwaste from the environment. Infiltration of rainwater was prevented by constructing a hall covering the whole single (northern) double-row of disposal boxes. After loading up this double-row completely, the hall will be disassembled and moved above the second double-row.

Strengthening of the stability of slopes (in southern direction from the second double-row of disposal boxes and north-east of the slope outside the repository site) was resolved by adding non-cohesive material at the slope foot, by densifying layers, and by adapting the resulting gradient of the slope at the ratio of 1:2.5.
By implementing these solutions, hazards and risks resulting from possible negative impacts on the safety of the repository have been completely eliminated.

HISTORY OF THE REPOSITORY CONSTRUCTION

The repository was built on the site of the Mochovice nuclear power plant (based on site selection process) since 1986. Initially terrain modifications needed for the preparation of the construction site were done, as well as access roads, power supplies and distributions of electric voltage and drinking water, and other facilities associated with the repository construction were built (1).

The construction itself started by building a clay sealing that provides the most important element separating the disposed radwaste from the environment (September 1986). To build it, clay originating directly from the construction site was used. Results of tests carried out since 1980 to 1984 confirmed that this clay could reach the required parameters out of which the most important - with regard to water migration - was the permeability coefficient that should be less than $10^{-9} \text{ m.s}^{-1}$.

The work at the construction of reinforced concrete structures of disposal boxes started by laying a gravel drain layer and by building fundament plates of individual dilatation modules in October 1987. Later on, the work continued by building walls of the individual boxes and was completed by laying a crane rail and reinforced concrete ceiling panels that covered the boxes. On the sides of the individual double-rows of reinforced concrete repository boxes, vertical clay sealing was built. The technology of its lying was verified and determined by a solidification test directly on the repository site.

In the course of the construction, also the quality of construction work was controlled. Both non-destructive and destructive concrete tests were performed. State testing institutions and experts from universities participated in the evaluation of these tests. Based on the total test evaluation it was possible to state that the concrete of repository boxes has the quality required which creates a good precondition for reaching the design lifetime of reinforced concrete structures. Test results of these structures led experts to the conclusion that the full static capability of boxes will remain maintained during 500 years as minimum.

Construction work on other objects proceeded simultaneously with the repository construction. Ditches and tanks for retention and removal of precipitation water, operational building, access and internal roads, and fences were built. In line with the progress of the construction work technology equipment of the repository was assembled as well – portal crane, monitoring equipment, instrumentation and control system, dosimetry equipment and other facilities.

This period of the repository construction was completed in November 1992.

The important fact representing the increase in requirements on the quality of the work carried out was that CSKAЕ Regulation No. 67/1987 about the assurance of nuclear safety during radwaste management came into effect and included radwaste repositories among nuclear installations.

As a result, number of changes was proposed and implemented with the objective to upgrade nuclear safety during radwaste disposal. The most important was a change in the disposal system. Barrels as an ultimate package for radwaste were replaced by, or used together with, fiber reinforced concrete containers, the integrity of which is guaranteed by the manufacturer for at least 300 years. The package considered originally – barrel with anticorrosive surface treatment had the lifetime ensured for only 30 – 50 years.
Review of the repository parameters was included in the Final Safety Analysis Report prepared in line with the internationally accepted NUREG 1199 guideline. The report was based on comparison of the design requirements and evaluation of all analyzed aspects associated with the repository (geology, hydrogeology, geotechnique, safety analyses, limits and conditions of safe operation and operating procedures, etc.). In line with the relevant legislation this report was submitted for review to UJD SR and also to other authorities in October 1993.

In December 1993, the UJD SR requested a review of the Final Safety Analysis Report for the Mochovce repository from the IAEA. The request was accepted and the IAEA sent a WATRP (Waste Management and Technical Review Program) mission to Mochovce. The mission was held on May 16-20, 1994. After studying design and safety documentation, after consulting with representatives of contractors, regulatory body staff and vendor, and based on walk-down of the repository construction, the mission issued a report in which the existing repository conditions were reviewed. Some enhancements were recommended in the area of design, operation, monitoring and safety analyses of the repository.

The UJD SR issued its position to the Final Safety Analysis Report on January 20, 1995. The regulatory body formulated its summary of requirements. To meet some of them, interventions into civil structures of the repository were required. They were mainly the following requirements:

- To develop a proposal of modifications and measures related to the drainage system in such a way that it would be possible to remove water from the individual disposal boxes and to measure activity of the water. (The system proposed by the original design made it possible to remove water, however, this water was collected in a common header and in the case of a contamination it was thus not possible to find from which box the contamination originated).

- To assure covering of the disposal area during the whole period of disposing. (This requirement resulted from the CSKAE Regulation No. 67/1987 according to which the areas into which radwaste is disposed should be dry, however, the solution with covering the boxes by ceiling panels failed to ensure this.)

After considering a few possibilities, the first requirement was resolved by building a new repository drainage system that is described below. The second requirement was resolved by building a steel hall above the first double-row of the repository. Following the filling up of the first double-row by waste, the hall will be disassembled and moved to the second double-row (3).

The implementation of this work represented a separate phase of the repository construction. Together with preparatory activities, the phase went from March 1996 till August 1998 within the project “Completion of the Mochovce repository” (3). The SLOVRAO company associating engineering, design and civil construction firms participated in it. The general designer was EGP Invest based in Uhersky Brod (Czech Republic) and the general supplier was VUJE Trnava Inc.

During the repository completion, also total reconstruction of civil structures was carried out and in order to improve the stability and resistance against erosion, a modification of southern side of the repository building itself and strengthening of the northeast slope outside the fence was carried out.

This phase of the repository construction and changes related to other aspects of the system for ultimate radwaste disposal were reviewed in the Final Safety Analysis Reports that was submitted to UJD SR for review in September 1998 (4). The Final Safety Analysis Report was elaborated based on comments and
requirements of UJD SR (April to June 1999). Based on this, UJD SR issued the approval for trial operation of the repository in Mochovce (November 1999).

DESIGN SOLUTION AND IMPLEMENTATION OF PROPOSED IMPROVEMENTS

The repository has been built 700 meters northwest from an abolished village of Mochovce (approximately 1.5 km in the same direction from the Mochovce nuclear power plant), at the end of a shallow valley drained by a right-hand tributary of Telinsky stream. It consists of a complex of constructions and technology equipment designed to handle radwaste since it arrival to the repository up to its ultimate disposal. The repository site (determined by fence) has the form of a trapezoid. The width of the site is 200 m and the maximum length is 650 m. From eastern, northern and western sides, the repository is enclosed by forest. The southern part is adjacent to agricultural soil. Forested mountain ridge around the repository reaches the maximum elevation of 270 m above see level. The repository bottom drops from 224 m at the northern side down to 206 m above see level at the southern side.

Design solution

The principal civil construction building is the repository itself. It consists of a sealing bath and of two double-rows of reinforced disposal boxes. They are built in the northern part of the site and oriented in the direction east - west. A single double-row consists of ten (2x5) modules (width 37.25 m, length 132.2 m) separated by insulation expansion slots. The expansion slots between the modules have 50 mm in width. Twenty disposal boxes are situated in a single row; four are in a single expansion module. The axial dimensions of the disposal boxes are 18 x 6 m, the internal dimensions are 17.4 x 5.4 m. Walls have variable height, the average height is 5.5 m. The thickness of the reinforced wall is 600 mm. At the longitudinal walls of the double-row, crane railway is fixed with the span of 18 m along which portal crane runs with the design load of 20 tons (designed for manipulations with containers).

Densified clay with required properties (water permeability coefficient $\leq 10^{-9}$ m.s$^{-1}$) is used as a principle sealing element separating the repository from the environment around it. The clay seal provides a “bath” into which the repository is inserted. Below the repository, a sand drain layer with the thickness of 0.6 m is provided, under which the bottom part of the clay bath with the thickness of 1 m is built.

Radwaste will be inserted into the repository in fiber reinforced concrete containers with the dimensions of 1.7 x 1.7 x 1.7 m and with the wall thickness of 0.1 m. The internal volume of each disposal box is designed for 90 containers. By using fiber reinforced concrete containers as the ultimate package of treated and conditioned radwaste (manufactured based on a French license), nuclear safety of the radwaste disposal system will be upgraded significantly. The protection is provided mainly by system properties enabling to maintain its stability and integrity during 300 years as a minimum (which is the proposed time interval of the repository institutional control). The total mass of a single empty fiber reinforced concrete container including its cover is 4300 kg. The mass of a filled container is estimated 10 000 kg in average.

During the completion of the repository construction in the period 1996-1999, also other measures for nuclear safety upgrading (3) were implemented, including coverage and reconstruction of the drainage system. In order to prevent infiltration of rainwater into the repository, the first double-row was covered by a steel structure with the dimensions of 52 x 156 m. The height of the hall is 16.75 m.
Fig. 1. Cross section of northern double-row of disposal boxes in Mochovce repository

The drainage system consisting of the system of controlled and monitored drainage was rebuilt to serve better for the removal and control of drain water from the repository area and its close vicinity.

**Draining Water Treatment**

- drainage water pumped from the original drainage layer
- water pumped directly from the storage boxes
- monitored drainage system
- activity supervision
- pump

Fig. 2. The scheme of drainage system and treatment of drain water
Controlled drainage

It is designed to remove water that could infiltrate into the repository (sand drainage layer in the boxes, or below the repository). To control and monitor this water, concrete tunnels (gallery) have been built along each row of disposal boxes making possible a controlled removal of water from each disposal box separately, and also from the sand drainage layer below the repository. The tunnels are walk-through corridors, illuminated and ventilated. In the area of crane long run-down, the tunnels are terminated by control reinforced shafts. Each shaft consists of four floors and equipment for tunnel ventilation, rooms for drain water sampling and collection of and manipulation with drain water are located in it.

Monitored drainage

It removes infiltrated water from the external side of the clay seal and from the space below the crane long and short run-down. The drainage is made out of flexible perforated tubes laid in sand bed. The drainage leads into a double-bath with stainless steel plate cladding and is fixed in reinforced sumps, one sump per each branch of the drainage.

Water from both controlled and monitored drainage is removed (pumped) through an underground channel into a drain water tank in which drain water from the repository surface is collected. From the drain water tank, water is discharged following a check via a drain channel and through Telinsky stream into Cifare pool.

The implementation of the drainage system in a mining way made it possible to built also a system for the control of clay moisture in the sealing bath and to check clay quality even after about 10 years since the construction of the clay sealing. This system is based on a set of stable passages incorporated in the shaft walls enabling access to selected points in the sealing bath and in turn also the extraction of clay samples for control tests of moisture.

Extraction points were built in regular distances of about 12 m along the shaft (10 extraction stations in each shaft). Each extraction station has three openings (passages) through shaft wall in which way a contact through clay of the sealing bath is provided. These opening are situated in the shaft bottom (floor) and in the shaft side wall at the elevation of 100 cm from the floor and shaft ceiling.

In the course of tunneling the shafts, clay samples were taken regularly and clay parameters including moisture were determined in laboratory. Totally 149 samples were taken (37 extractions per shaft). The average moisture from all samples taken lays in the following intervals (4):

- 18.1 % to 19.4 % for the extraction points No. 1 – in shaft floor
- 17.8 % to 18.5 % for the extraction points No. 2 – in side wall
- 17.7 % to 18.9 % for the extraction points No. 3 – in shaft ceiling

From statistical evaluation of the samples taken, 95 percent probability results that the natural moisture of any clay sample from the clay bath is in the interval of 16.7 % to 19.3 % and it thus lays in the interval of optimum moisture.

It is thus possible to state that the results of clay moisture monitoring in the sealing bath as implemented in the course of constructing the monitoring shafts confirmed the assumptions about satisfactory dispersion of
the values of clay moisture in the sealing bath. Also, the results of verification of the filtration coefficient of the clay sealing were favorable in a similar way – the values revealed were $< 10^{-9}$ cm.s$^{-1}$.

The realization itself of the objects implemented that should improve the total parameters of nuclear safety of the Mochovce repository is shown in Figs. 3 and 4.

Fig. 3. Stainless steel hall covering the first double-row in the Mochovce repository
THE SYSTEM OF MONITORING, ITS OBJECTIVES AND SCOPE

The repository is classified as a nuclear installation. One of the conditions for issuing approval for trial operation of a nuclear installation is to have an approved “Program of radiation control of the environment around nuclear installation” (5). By means of which the operator should demonstrate its ability, both technically and with regard to human resources, to monitor the radiation situation around the nuclear installation. The operator should be able to document that the nuclear installation has no negative impact on the environment or respective to be able to reveal such an impact early and take necessary corrective measures.

The objective of monitoring

The objective of the monitoring is to reveal and evaluate early any undesirable change in the parameters of repository (predominantly water presence in the disposal boxes) that in long-term effects could result in infiltration of radio nuclides into the environment and in turn to cause exceeding of the authorized limit for the exposure of the public. It is thus not an environmental monitoring in the broadest sense, but a monitoring focused mainly on the observation of the impact of particular activities (in the operational phase) or of objects on the environment. It is necessary to account for a relatively limited range of potentially releasable radioactive nuclides in terrestrial components of the environment (forest and fields close to the repository and irrigated fields).
The scope of monitoring

- The scope of the monitoring (6) during repository operation is determined by requirements of the legislation in force, which can be summarized as follows:
  - control of authorized limits specified for repository operation (mainly activity of drain water),
  - documentation of nuclear safety and barrier stability and of the affected environment (underground water),
  - documentation of radiation situation around the repository in the course of waste disposal,
  - detection of non-acceptable release and migration of radio nuclides in the environment sufficiently in advance so that appropriate corrective measures could be taken.

The monitoring system of radiological parameters is split into two main parts:

- monitoring of drain, underground, and surface water,
- monitoring of atmosphere, soil and food chains.

Water and the associated hydrosphere is considered as a decisive component of the environment by means of which radionuclides can get from the repository into the surrounding environment. Early warning against potential releases from the repository in the monitoring program is achieved by a sufficiently frequent measurement and evaluation of $^3$H and $\sum \beta$ activity in water samples from:

- drain system,
- particular drill holes of underground water,
- surface water from Telinsky stream upstream and downstream Cifare pool and its tributary C.

In longer time intervals (once a year), samples are analyzed for the content of other significant radio-nuclides in the environment (isotopes $^{137}$Cs, $^{90}$Sr, $^{239}$Pu, $^3$H, $^{14}$C, $^{129}$I) in samples of:

- joint evaporated parts from underground and surface water,
- bed sediments from Cifare pool and in tributary C,
- soil on the repository site and around it.

The evaluation of monitoring results

The principle part of the monitoring program is provided by statistical methods for the evaluation of natural variability of the radiation background and for the demonstration of the repository performance by means of testing statistical hypotheses. The background radioactivity level on the site during the period of repository operation and following its closure will interfere with the level of radio-nuclides that could theoretically be released from the waste disposed. A set of data from pre-operational monitoring of background levels collected prior to the beginning of active operation of the repository thus provides a basis for the determination of original conditions for these purposes.

The program of radiation control around nuclear installation also includes the results of pre-operational monitoring of radiation situation around nuclear installation prior to its commissioning as a basis for the evaluation of possible deviations in the monitoring following the commissioning of the nuclear installation. These results characterize real swings in the radiation background in the monitored buildings on the site and
appropriate statistical parameters were used to deduce criteria for the evaluation of results of operational monitoring in relation to issuing early warning against degradation of repository performance (7).

**Background criteria** are specified for directly measured quantities in relation to the background data set with mean value $B$ and standard uncertainty $s$, as certain maximum value of this distribution, $B_c$, and a value $B_m$ exceeding this background that comply with the two required conditions:

1. the risk $\alpha$ that in case of a non increased background level, the measured value will get above the critical background level $B_c$, or on other words, that the error $\alpha$ of type I will be sufficiently low, e.g., $\alpha = 0.05$, and
2. in the case when the monitored quantity is really increased and its actual level exceeds the $B_m$ value, the exceeding of the critical background value $B_c$ recorded by the first set of measurement will be confirmed also by the next repeated measurement with a sufficiently high probability $(1-\beta)$ which means that the error $\beta$ of type II is also at a reasonably low level e.g., $\beta=0.05$.

According to these conditions, the value of $B_m$ in fact meet the well known probabilistic definition of the detection limit of a measuring system (MDA) according to the Curie approach (8), i.e. $B_m = \text{MDA}$, and $B_c$ can be expressed as a certain $\alpha$-quantile of the distribution of background data, and if $\alpha = \beta$, then

$$B_m - B \equiv 2(B_c - B) \quad \text{(Eq.1)}$$

In the monitoring program, also the reference levels for the evaluation of monitoring results are derived based on the results of pre-operational monitoring:

**Recording level** - with regards to the character of expected data, all data obtained from the monitoring are recorded. The results of the „less than“ type, such result of measurement is declared if the number of impulses does not exceed the critical level of the number of impulses of the measurement system in question. By means of methods of sequential statistics, even such data can help in quantifying the background level close to the detection possibilities of the method applied.

**Investigation level** - As an investigation level, the above mentioned value was accepted of the minimum detectable activity of the monitoring system $\text{MDA} = B_m$, derived according to periodically updated statistical parameters of the background set for the repository.

The initial statistical parameters characterizing the appropriate background set prior to the repository commissioning were used for the derivation of the appropriated reference levels – critical background value

$$L_c = B_c - B = k_{\alpha} \cdot s \cdot \sqrt{2} \quad \text{(Eq.2)}$$

and minimum detectable activity

$$\text{MDA} = B_m \equiv B + 2L_c \quad \text{(Eq.3)}$$
For the particular monitored parameters, the derived background reference levels are summarized in Table I.

CONCLUSIONS

The improvements implemented during the completion of the Mochovce repository with the objective to upgrade its nuclear safety are described in the paper. These improvements relate to the prevention of infiltration of rainwater into the disposal areas (boxes) in the course of repository operation and the facilitation of the control of water presence in the individual boxes, their control and removal. They were implemented based on recommendations of the WATRP mission and requirements of UJD SR. The prevention of rainwater infiltration into the disposal boxes during repository operation was implemented by building a steel hall above the first (northern) double-row. The implementation of the second requirement to rebuild completely the drainage system the main part of which are monitoring shafts built along the disposal boxes from outer side in the vertical wall of the clay bath with the width of 3.5 m. During the repository completion, the proposed and justified modifications of two slopes (southern and north-eastern) providing enhancement of their anti-erosion stability were also implemented.

Also the results of pre-operational monitoring are shortly shown in the paper and reference levels for the investigation of deviations from radiation background are derived which could be related with the radwaste repository.

REFERENCES

3. Supplement to UP and supplement to VP: Completion of the Mochovce Repository, EGP INVEST, design office Trnava, 1997 – 1999
### Table I. List of parameters of reference levels for Mochovce repository monitoring program

\[ N \text{ amount of measurement, } B_C = B + 1.65 \sqrt{2}, \quad \text{MDA} = B_m = B + 3.3 \sqrt{2} \]

<table>
<thead>
<tr>
<th>Monitored parameter</th>
<th>Units</th>
<th>Amount N</th>
<th>Average B</th>
<th>Standard uncertainty s</th>
<th>B_C</th>
<th>MDA=B_m</th>
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<td><strong>Underground water – horizon H</strong></td>
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<td>Total beta volum.</td>
<td>Bq/l</td>
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<td>0.17</td>
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<td>$^3$H</td>
<td>Bq/l</td>
<td>69</td>
<td>6.4</td>
<td>1.5</td>
<td>9.90</td>
<td>13.40</td>
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<tr>
<td>$^{40}$K</td>
<td>Bq/l</td>
<td>54</td>
<td>0.14</td>
<td>0.06</td>
<td>0.28</td>
<td>0.42</td>
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<td>0.25</td>
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<td>0.55</td>
<td>0.4</td>
<td>1.48</td>
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<td>$^3$H</td>
<td>Bq/l</td>
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<td>6.4</td>
<td>1.5</td>
<td>9.90</td>
<td>13.40</td>
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<tr>
<td>$^{40}$K</td>
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<td>0.15</td>
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<td>0.23</td>
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<td>Bq/l</td>
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<td>0.009</td>
<td>0.05</td>
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<td><strong>Cifare pool and Telinsky stream</strong></td>
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<tr>
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<td>0.95</td>
<td>0.5</td>
<td>2.12</td>
<td>3.28</td>
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</table>

### Dose rates on repository site

| Dose rate, site | nGy/h | | | | |
| Dose rate– TLD, site | nGy/h | | | | |

1. According to VUJE data from 1991
2. Estimated according to $^{40}$K (70 %)