Disposal of Spent Nuclear Fuel from NPP Krško

Irena Mele
ARAO – Agency for Radwaste Management
Parmova 53, SI-1000 Ljubljana, Slovenia
irena.mele@gov.si

ABSTRACT

In order to get a clear view of the future liabilities of Slovenia and Croatia regarding the long term management of radioactive waste and spent nuclear fuel produced by the NPP Krško, an estimation of disposal cost for low and intermediate level waste (LILW) as well as for spent nuclear fuel is needed. This cost estimation represents the basis for defining the target value for the financial resources to be accrued by the two national decommissioning and waste disposal funds, as determined in the agreement between Slovenia and Croatia on the ownership and exploitation of the NPP Krško from March 2003, and for specifying their financial strategies.

The one and only record of the NPP Krško spent fuel disposal costs was made in the NPP Krško Decommissioning Plan from 1996 [1]. As a result of incomplete input data, the above SF disposal cost estimate does not incorporate all cost elements. A new cost estimation was required in the process of preparation of the Joint Decommissioning and Waste Management Programme according to the provisions of the above mentioned agreement between Slovenia and Croatia.

The basic presumptions and reference scenario for the disposal of spent nuclear fuel on which the cost estimation is based, as well as the applied methodology and results of cost estimation, are presented in this paper. Alternatives to the reference scenario and open questions which need to be resolved before the relevant final decision is taken, are also briefly discussed.

1 INTRODUCTION

Disposal of spent fuel (SF) and high level waste in deep geological formations is considered the only technically acceptable and safe permanent solution. This solution has been adopted by all countries that have clearly defined programs for long term SF and HLW management. However, no country has yet built a repository for spent fuel and HLW. Finland and USA have come very close to a final resolution. They are in the course of characterizing the selected location while Sweden is still deciding between the two potential sites.

Based on data obtained from other countries, the construction of a deep geological repository presents a technically and financially very demanding operation. It is important to elaborate the disposal option and prepare the cost estimation in time in order to make the necessary provisions for covering future liabilities.
While the disposal option for low and intermediate level waste has already been well elaborated and the preliminary cost estimation is already prepared, the disposal of spent nuclear fuel has not been dealt with either in Slovenia or in Croatia. Both countries were focused primarily on the siting and construction of the low and intermediate level waste repository. The issue of the SF program has not been on a priority list. According to the provisions of the Spent Fuel and High Level Waste Management Strategy [2] - which was adopted by the Slovenian Government in 1996 – this decision has been postponed until year 2020. Only the agreement from 2003 between Slovenia and Croatia on the ownership and exploitation of the NPP Krško, stimulates new investigation of the disposal strategy.

In 2004 the Joint Decommissioning and Waste Disposal programme [3] was prepared by the Slovenian and Croatian Waste management organizations. Although the Joint Programme is primarily aimed at providing a good estimation of future liabilities of the NPP Krško, it also gives the first more detailed elaboration of spent fuel disposal option and its cost assessment.

2 REFERENCE SCENARIO: DEVELOPMENT OF A REPOSITORY

Since neither Slovenia nor Croatia has developed a disposal concept for SF, the Swedish concept of disposal in hard rock and its cost analysis method has been taken as a reference for the SF repository cost assessment [4]. The reasons for such an approach were as follows:

- Sweden has the most developed waste disposal concept. The same disposal concept has been adopted by Finland [5], the first European country to construct its own SF repository.
- Sweden has a highly advanced cost assessment methodology with well defined cost elements.

The selected spent fuel disposal concept is called a reference scenario. It is developed on the following presumptions:

1. The operating lifetime of the NPP Krško will end in 2023.
2. Only direct disposal of spent nuclear fuel is considered (no reprocessing).
3. The repository will be constructed in hard rock environment at a depth of 500 m. The repository concept and entire disposal system are based on the Swedish KBS-3 concept, developed by Swedish Spent Fuel Management Agency (SKB).
4. The estimated spent fuel quantity at the end of the planned NPP Krško life time is based on the future 18-month fuel cycle schedule.
5. The repository is planned for 1531 ± 20 fuel assemblies or 620 tons of heavy metal, as well as for a small quantity of HLW generated during NPP Krško decommissioning (~16 m³).
6. In accordance with the operating lifetime of the NPP two alternatives of the reference scenario have been considered:
   a) Alternative 1: start of repository operation in 2030. Until then the SF is stored in the spent fuel pool at the premises of the NPP.
   b) Alternative 2: start of repository operation in 2050. Until then interim dry storage of SF.

The reference scenario is made for a generic location in hard rock media. Where required, area-specific magmatic and metamorphic rock properties are applied.
3 DESCRIPTION OF REPOSITORY

Reference scenario [6] includes only those elements which are directly connected to the disposal activities. It does not address either pre-disposal spent fuel management or off-site infrastructure. However, besides the repository it also includes an encapsulation plant for spent fuel as an important element of a disposal concept.

3.1 Encapsulation of spent fuel

It is assumed that spent fuel will be encapsulated according to the Swedish concept. Fuel assemblies will be inserted and sealed into massive copper or steel canisters. The canister is a 1 m-diameter and 5 m-high cylinder with 5 cm-thick anticorrosion overpack of copper. From the inside it is reinforced by a cast iron insert which can accept four PWR fuel assemblies. The weight of a canister filled with SF is about 25 t.

Based on provisions of the reference scenario, canisters are procured by an outside supplier rather than being manufactured locally. Their quantity requirements are based upon residual heat data of the spent fuel assemblies from previous cycles [7], [8], [9] and upon estimated residual heat data of spent fuel assemblies from future cycles. Since the heat release in the year 2030 is still quite high, most of canisters can be filled with only two or three fuel assemblies instead of four. Having also in mind that a few dozens of canisters have to be purchased for testing purposes (welding technology), for the first alternative (repository in 2030) 750 canisters are needed, and for second alternative (repository in 2050) 450 canisters. Procurement is foreseen as a phase by phase process to be completed within eight and seven years respectively, first canisters to be dispatched two years before start of the repository operation.

Encapsulation is planned to be performed in the encapsulation plant located at the repository site. The plant will contain units for acceptance of transport containers, for encapsulation, for dispatching and transportation of canisters to underground disposal facilities, office building and auxiliary facilities and systems.

The encapsulation plant has a capacity of 200 canisters per year. Its operation should start one year prior to start of the deep repository operation. The overall operation period of an encapsulation plant depends upon the number of canisters to be filled up and welded. After two years’ test operation, personnel training and test welding of a few dozens of canisters, encapsulation of all spent fuel assemblies would be completed within a six - or four - year period respectively.

At the end of operation, the encapsulation plant will be dismantled and its contaminated parts processed as radioactive waste. No considerable quantities of radioactive waste are expected. The dismantling should be finished within three years.

3.2 Repository

The deep geological repository consists of underground facilities and a number of above ground facilities, which are indispensable for normal underground repository operation. The surface part is connected with the underground part through access shafts and a waste transportation ramp, as presented in Figure 1.
According to the reference scenario the surface part of the repository consists of the following buildings:

- operations building
- storage building
- garage building
- maintenance and service building
- ventilation building
- production building for high-pressure compacting of bentonite and preparation of backfill materials
- office and workshop building
- information center
- rock stockpiles.

The underground part of the repository is situated at a depth of 500 m below the ground surface. It consists of two areas: central service area and disposal area. The underground level can be reached in several ways: for personnel through the service shaft, for waste and other cargo through the spiral ramp (with at least 15 m curve radius and 10 % slope). The ramp is 5 m long, 10 m wide and 7 m high. The service shaft has 5 m in light profile. It contains two elevators, the large one for personnel and small size loads and the small one for emergency exit. The service shaft is also used as part of the ventilation system (air intake). The repository is supplied with a 3 m wide ventilation shaft which can serve as an emergency exit as well. Access shafts lead towards the central service area located directly below the operations area on the surface. Service area dimensions are 190m x 100m. Beside shaft stations, there are four 60 m long, 12 m wide and 10 m high underground halls. The central
service area contains equipment for unloading of canisters, their transportation to disposal tunnels; it is equipped for acceptance, storage and transportation of bentonite blocks and other items. There is also a maintenance vault intended for maintenance and repairing of underground facilities and equipment, vehicle vault, storage vault, utility vault and drainage vault.

![Diagram of disposal tunnel layout](image)

**Figure 2** Canister Disposal in Tunnel Boreholes (from ref. [6]).

The central service area is connected with the disposal area which consists of two sections of parallel disposal tunnels. The tunnel spacing is 40 m. Canisters are deposited into 1.8 m diameter disposal boreholes at the bottom of each tunnel and surrounded by 35 cm thick layer of compacted betonite, as shown in Figure 2. Each borehole contains one canister; in the reference scenario each tunnel has 21 boreholes with 9 m spacing between them. The spacing was defined on the basis of thermal analysis made for Aberg [7], which has a similar thermal conductivity and a boundary condition of 90°C on the canister surface. The tunnel length is 207 m. The number of disposal tunnels depends on the number of canisters. In alternative 1 there are 34 disposal tunnels (total capacity of 714 canisters), and 20 disposal tunnels (total capacity 420 canisters) in alternative 2.

Planned repository operation is 7 years (start in 2030) and 5 years respectively (start in 2050). Disposal of spent fuel will start during the second year of repository operation. Total quantity of 710 or 420 canisters will be deposited within six or four years. The disposal schedule will be harmonized with encapsulation schedule. As soon as the disposal tunnel is filled up, it will be backfilled by a 15/85 compound of betonite and sand. Backfilling of the entire disposal area will be completed within 1 year after the terminated operation period.
4 COST ESTIMATE OF REFERENCE SCENARIO

The cost estimate is based on Swedish methodology [4]. It has been slightly modified to fit our needs (schedules, waste quantity and type, repository capacity, etc.). The whole project is divided by facilities and by tasks:

- encapsulation plant
- repository surface facilities
- repository underground and access facilities.

According to Swedish cost assessment methodology, site selection and site characterization costs are added to costs of the surface part of the repository. In the reference scenario it has been assumed that site selection will be completed in 6 years and site characterization within the following 7 years.

An itemized cost estimate has been made for investment costs, operation costs and backfilling and decommissioning costs. Item “other costs” contains costs related to site selection and characterization, monitoring and compensations to the local community. VAT is not included. Item “contingencies” (30% of total amount) has been added due to unreliable input data, assumption-based estimates, time distant activities and due to fact that this cost estimate is not based on the actually made project.

**Table 1** Reference Scenario – Deep Geological Repository Cost Estimate (undiscounted, VAT excluded)

<table>
<thead>
<tr>
<th>Costs (in mio €)</th>
<th>Alternative 1 Repository 2030</th>
<th>Alternative 2 Repository 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INVESTMENT COSTS</strong></td>
<td>207.2</td>
<td>191.2</td>
</tr>
<tr>
<td>Off site infrastructure &amp; equipment</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Encapsulation plant</td>
<td>81.2</td>
<td>81.2</td>
</tr>
<tr>
<td>Repository- surface facilities + equipment</td>
<td>37.4</td>
<td>37.4</td>
</tr>
<tr>
<td>Repository-underground facilities + equipment</td>
<td>87.3</td>
<td>71.3</td>
</tr>
<tr>
<td><strong>BACKFILLING &amp; DECOMMISSIONING</strong></td>
<td>28.2</td>
<td>20.5</td>
</tr>
<tr>
<td>Encapsulation plant</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Repository – surface facilities</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Repository – underground facilities</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Backfilling</td>
<td>24.6</td>
<td>17.0</td>
</tr>
<tr>
<td><strong>OPERATING COSTS</strong></td>
<td>99.0</td>
<td>62.4</td>
</tr>
<tr>
<td>Encapsulation plant</td>
<td>69.6</td>
<td>42.4</td>
</tr>
<tr>
<td>Repository</td>
<td>29.4</td>
<td>20.0</td>
</tr>
<tr>
<td><strong>OTHER COSTS</strong></td>
<td>124.4</td>
<td>118.0</td>
</tr>
<tr>
<td>Monitoring</td>
<td>4.8</td>
<td>4.0</td>
</tr>
<tr>
<td>Siting and R&amp;D</td>
<td>82.0</td>
<td>82.0</td>
</tr>
<tr>
<td>Compensation costs</td>
<td>37.6</td>
<td>32.0</td>
</tr>
<tr>
<td>Contingencies 30 %</td>
<td>137.6</td>
<td>117.6</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>596.4</td>
<td>509.7</td>
</tr>
</tbody>
</table>

This cost estimate does not deal with spent fuel pre-disposal and transportation costs; these are incorporated in NPP decommissioning costs. Research and development costs are not dealt with separately, since they are part of “site selection and characterization” item. The cost estimate of compensation to the local community for limited land use is based on the
Slovenian Ordinance on compensation criteria for limited land use in the area of a nuclear facility (Official Gazette of RS No. 134/2003), since the issue of compensation for nuclear facilities has not been addressed in Croatia.

The disposal cost distribution, inclusive of compensation and contingencies, is similar for both alternatives. For a repository in 2050 it is shown in Figure 3. A gradual increase of costs is registered from 2010 or 2030 with start of the site selection process. There is a significant increase in costs a few years prior to start of repository operation, when the construction starts, and then a rapid decrease already during operation and additional decrease during closure and decommissioning.

5 ALTERNATIVES

Due to high costs associated with development of a spent fuel repository, it is not likely that each nuclear country will build its own repository. Countries with smaller nuclear programs hope to be able to use “multinational”, shared repositories to be developed in parallel with national repositories. Disposal of large quantities of waste originating from different countries in such a repository should lower per unit costs of disposal and more easily provide the required safety of the facility and of the disposed waste.

In spite of the numerous benefits that a shared spent fuel and high level waste repository might have, no initiative so far has been successful. Many countries are even strongly opposed to it. At present the only alternative to the national repository development is an export of spent fuel to Russia. This possibility has been open since 2001, when the Russian Federation (RF) adopted a package of three acts, on the basis of which import of irradiated fuel assemblies from other countries’ nuclear reactors to the Russian Federation for storage and/or reprocessing has been made possible. By these acts the ban on import of irradiated foreign origin nuclear fuel has been abolished. It was decided that this subject be treated through future commercial contracts.
An export of spent fuel without re-export of reprocessing residue might be an applicable option for NPP Krško spent fuel. There is, however, a question of price and economical justification that remains open. In recent years there were some preliminary discussions with Russian representatives, which give some insight into prices for reprocessing of SF and re-export of HLW residues and for permanent export of SF. At present, the cost of permanent export substantially exceeds the cost of construction of a repository. There are also other issues which need to be resolved before the export of SF to Russia could be considered acceptable, such as:

- permanent export provision in the international agreement on peaceful use of nuclear energy between Slovenia and RF, which is a requirement for entering into commercial SF export contracts, and
- the consent right of the USA to the export of nuclear fuel. According to US DOE, the ex-Yugoslavia belonged to group of countries which required such permission.

Detailed investigation is needed also in relation to the transfer of title to SF and responsibilities related to such title having in mind the present dual ownership of SF. Since the Russian proposal exclusively addresses the import of spent fuel, an export of expected small quantities of high level waste and long lived LILW from the decommissioning should also be agreed.

6 CONCLUSIONS

For the purpose of the Joint Decommissioning and Waste Management Programme the concept of spent nuclear fuel disposal was developed and a cost estimate for two alternatives – repository in 2030 and repository in 2050 – was prepared. The repository concept closely follows the Swedish concept of disposal in hard rock. The repository is planned at a depth of 500 m below ground. The access is provided through a 5 km ramp and two vertical shafts. The spent fuel is disposed of in copper canisters in boreholes drilled at the bottom of underground tunnels. Packaging of spent fuel takes place in an encapsulation plant which is located at the repository site. Additionally a third option - an export of SF to Russia - was also analysed. All three options were financially estimated and compared. The total cost as well as the discounted cost show a clear preference for the repository which would be in operation only in 2050 or later.

REFERENCES

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[9] RAWRA - Thermal calculations of the layout of disposal wells in a Czech geological repository, ŠKODA JS s.r.o., Czech Republic, 2000