Spent Fuel Management in Slovenia: Current Status and Future Plans

Nadja Železnik, Leon Kegel
ARAO-Agency for Radwaste Management,
Parmova 53, Ljubljana, Slovenia
nadja.zeleznik@gov.si, leon.kegel@gov.si

ABSTRACT

Slovenia adopted in 1996 the first Strategy on spent fuel (SF) management in which general directions how to manage SF from Nuclear Power Plant Krško (NEK) and research reactor TRIGA were given. In 2006 Resolution on radioactive waste and SF management for period 2006-2015 was accepted, where more precise short term programs for SF management were described. Long term approached to NEK spent fuel management have been elaborated in several revisions of Decommissioning, Radioactive waste and Spent fuel management program for NPP Krško prepared based on the Agreement between the governments of Slovenia and Croatia on the status and other legal issues related to investment, exploitation, and decommissioning of the NEK (Agreement). In scope of this work also new studies for spent fuel storage and disposal were prepared in which technical solutions were analyzed and proposed for specific spent fuel (SF) from NEK. Time schedules for main activities of SF storage and disposal development were elaborated for two alternative scenarios which correspond to normal NEK operation and 20 years lifetime extension. All technical activities were financially assessed and costs estimates of SF storage and geological disposal development provided. The prepared studies were verified by international experts in order to confirm the correctness of technical inputs, proposed solutions, time schedules of activities and costs evaluations. The calculated nominal and discounted costs of spent fuel management served for the recalculation of annuities in the integral scenarios of interrelated activities on NEK decommissioning, LILW and SF management.

Additionally, the operator of research reactor TRIGA started with investigations of possible further use of TRIGA reactor after 2016 which represents the deadline for the shutdown in order to return spent fuel rods to USA. All variants have to be technically evaluated, financially assessed and compared. Based on findings the proposition for further destiny of research reactor has to be adopted by responsible institutions.

The paper presents the current development and solutions in Slovenia regarding spent fuel management, open questions which need to be solved and future development in the SF management. The overview and findings will be introduced in the new version of National program on radioactive waste and spent fuel management in Slovenia which will be drafted in 2014.

1 INTRODUCTION

Slovenia has a very small nuclear program: one nuclear power plant Krško (NEK) in co-ownership with Croatia in the 50:50 share located in Krško, one central interim storage facility for radioactive waste from small producers (medicine, industry and research) and one research reactor TRIGA, both at same location Brinje near capital Ljubljana.

Slovenia has adopted several document related to SF management. In 1996 first Strategy on SF management was accepted with some general direction how to manage all SF. According to this strategy, the decision on the final solution of SF disposal in the Republic Slovenia should be adopted by 2020, while the siting and the construction of the repository should be finished by the year 2050. Until then the fuel should be stored in the NEK spent fuel pool or in dry storage.

The strategy was superseded in 2004 due to the Agreement on the status and other legal issues related to investment, exploitation, and decommissioning of the NEK (Agreement) which
entered into force in 2003. On the basis of the Agreement, Slovenia and Croatia jointly prepared and approved a revision 1 of the Program for Decommissioning and Disposal of LILW and High Level Waste of NEK (Decommissioning Program) in 2004. In accordance with requirements from the Agreement that the new revision of the document should be adopted every 5 year, in 2008 the preparation of revision 2 of the Decommissioning Program started and is now under revision process from all involved stakeholders. In parallel, Slovenia has adopted new with EU directives harmonized nuclear law in 2002 and accepted in 2006 Resolution on radioactive waste and SF management for period 2006-2015 which includes all relevant topics for the management of the radioactive waste and spent fuel, from the legislation and identification of different waste streams in Slovenia, to the management of radioactive waste and spent fuel, the decommissioning of nuclear facilities and management of naturally occurring radioactive materials. For the SF management 2 operational programs are included: one for NEK and the other for TRIGA reactor. In case of NEK the capacities for spent fuel storage pool are sufficient till the end of the NPP planned lifetime until 2023. In case of NPP lifetime prolongation until 2043 the re-racking is planned. Future management of SF is based on the Decommissioning Program which includes also interrelations and interdependences of all activities for safe and secure SF management. Disposal of spent fuel will not start before 2065, for the period between end of NEK operation and start of disposal operation dry storage of SF is foreseen. For TRIGA research reactor the resolution foreseen that decision on the operation period should be taken by the operator which should consider the possibility to return spent fuel rods to USA, the origin of fuel. While the USA takes back the spent fuel until 2019, the reactor should be shut down in 2016 at latest in order to cool down the fuel. In case that the operator will not decide on the return of spent fuel to USA and will continue with TRIGA reactor operation after 2016, the solutions for SF management have to be provided including storage options.

2 TECHNICAL SOLUTIONS FOR SF MANAGEMENT

2.1 NPP Krško

The NEK is one of the main pillars of the Slovenian power system. It is situated on the left bank of the Sava River in Krško. It started operating in autumn of 1981 and has been operating commercially since 1983. NEK is a Westinghouse two-loop Pressurized Water Reactor with nominal output power 727/696 MWe (gross electrical power/net electrical power). The plant is owned by state-owned Slovenian and Croatian electrical power companies, GEN energija d.o.o. and Hrvatska Elektroprivreda -HEP d.d., respectively. All operational radioactive waste and SF are stored within the plant area. All radioactive waste is treated and then packed into steel drums, which are then stored in the solid radwaste storage facility. The reactor core is composed of 121 fuel assemblies. Each fuel element consists of 16x16 fuel rods, top and bottom nozzles, grid assemblies, control rod guide thimbles and instrumentation guide thimbles. The fuel rods contain ceramic uranium dioxide pellets welded into zircaloy-4 or ZIRLO tubes and enriched with U-235. Every 18 months approximately a half of the fuel assemblies are removed and fresh fuel is loaded. Fuel assemblies remain in the reactor core for three years. Spent fuel assemblies are kept under water in the spent fuel pool, where they are cooled. The capacity of the pool has been enlarged in 2003 – from the previous 828 to present 1694 fuel assembly locations. At the end of 2010 there were 984 SF assemblies stored. The SF inventory was assessed for two variants - for originally planned 40-year operation (until 2023 – Variant 1) and for 20-year extended lifetime (until 2043 – Variant 2) – taking
into account continued 18-months fuel cycles. The latest estimation of total number of spent fuel assemblies generated in 40-year operation is now 1553 (620 metric tons of metallic uranium). For the extended lifetime until the year 2043 a total number of 2281 fuel assemblies (or 912 metric tons) have been calculated. The inaccuracy is estimated to be ± 20 assemblies. It is foreseen that NEK will assure sufficient on site SF storage in the pool until the end of NPP lifetime when decommissioning will start. Additionally approximately 36 m$^3$ of high level waste will be produced.

2.1.1 Long term storage of SF

The following assumptions and requirements were considered when investigating different SF storage options for SF from NEK after its shut down:

- Only dry SF storage options are considered and investigated due to immediate dismantling strategy as taken in Preliminary Decommissioning Plan for NPP Krško [1].
- Only one SF storage is considered for all SF (the question is relevant due to the co-ownership of NPP between Slovenia and Croatia).
- The site for SF storage is generic. Site selection is not included in the cost assessment.
- Provisions for SF transportations have been considered when evaluating different storage options and rough cost estimate for the transfer of SF to the storage facility is included.

Several dry storage options have been investigated for the purpose [2] like vault type dry storage, concrete modules, metal casks. All licensed dry spent fuel storage facilities provide subcriticality, confinement, radiological shielding, physical protection, and inherent passive cooling of the spent nuclear fuel during normal, abnormal and accident conditions. Dry storage methods rely on metal or concrete for shielding radiation from spent fuel assemblies, which continue to emit considerable decay heat that must be dissipated to the atmosphere. When evaluating different storage options, the following criteria were taken into consideration regarding technology:

- must be well proven with possibility for storage lifetime extension beyond 50 years,
- should provide the possibility of using the facility also for storing of HLW,
- should allow the adjustment of the storage capacity (i.e. in case of decision for second NPP unit) as well to the site,
- and should be cost effective.

Based on comparison of characteristics, the CASTOR V/19 metal casks have been selected for packaging of SF. The CASTOR V cask was developed to hold spent pressurized water reactor or boiling-water reactor fuel with a decay time after loading of the cask of approximately five years. The design is based on the International Atomic Energy Agency requirements and recommendations and in accordance with predefined requirements, such that the casks conform to all international standards and regulations for public transportation by road, rail or sea. The V/19 casks accept 19 PWR spent fuel elements. Depending on the NEK lifetime 82 CASTORs or 121 CASTORs will be needed.

The building for dry CASTOR storage is assumed as a simple building with a capacity of 90 CASTORs or 130 CASTORs respectively (small redundancy in capacity). The ground plan of the storage facility is 2.500 m$^2$ (or 3.600 m$^2$ for the case of extended NPP Krško lifetime) with 12 m height. The foundation should carry the weight of 120 tons per CASTOR cask. The facility is designed with several compartments and 120 tons cranes for manipulation of CASTOR casks. The facility has no active systems. All required safety functions are provided by the CASTOR casks (sub criticality, radiation protection, heat dissipation). Casks are stored...
in an upright position and sufficient space must be provided between them to allow the necessary heat transfer by natural convection. Part of the storage facility is also a hot workshop for safety checks and repairing actions (to provide conditions to open first and second cover of the CASTOR containers).

It is assumed that the storage facility will be available immediately when the NPP Krško will stop its operations (in 2023 in Variant 1 and 2043 in variant 2). The start and duration of main activities related to SF storage for both variants is given in figure 1. Empty CASTORs after re-packing will be disposed of in the geological repository (in service areas).

**Figure 1.** Time dependence of activities related to SF storage and repository for 2 variants

### 2.1.2 SF disposal

New revision of SF disposal study [3] has been prepared, as a semi-generic description of geological repository in hard rock suited to the needs of the NEK SF, HLW and some long lived low and interim level radioactive waste (LL-LILW). It includes all phases of repository development including research activities, siting, construction, operation and closure. The analyzed scenarios are prepared in two variants. The SF disposal is based on the following assumptions:

1. Only direct disposal of SF (no reprocessing);
2. The repository will be constructed in hard rock environment at the depth of 500 m; the entire disposal system remains based on the Swedish KBS-3V concept, developed by Swedish Spent Fuel Management Agency (SKB);
3. The repository development includes also the construction and operation of an underground testing facility at the site of future repository;
4. Sufficient cooling period is required prior the disposal to allow optimal utilization of canister capacity (4 SF elements per cooper canister);
5. Disposal of SF starts after 45-year storage period (variant 1 or variant 2).

The deep geological repository consists of underground facilities and a number of above ground facilities, which are indispensable for normal underground repository operation. The underground part has two areas: central service area and disposal area. It is connected to the surface part through access shafts and a waste transportation ramp.
The disposal area at a depth of 500 meters consists of a number of disposal tunnels, conventionally excavated by means of drilling and blasting. From the bottom of each tunnel, vertical boreholes are drilled with due spacing regarding heat distribution around the canister. Canisters are lowered into the holes and surrounded by a layer of bentonite clay called a buffer, since it protects the canister against small movements in the rock and keeps it in place. The disposal tunnel is continuously backfilled with a mixture of crushed rock and bentonite in step with the progress of emplacement of the canisters. Encapsulation plant is part of the reference disposal concept. Packaging of SF also follows the Swedish model. Fuel elements are inserted and sealed in massive copper canisters with cast iron inserts in encapsulation plant. Based on provisions of the reference scenario, canisters are procured by an outside supplier rather than being manufactured locally. Figure 2 illustrates the copper disposal canisters, and the overall layout of the repository.

![Figure 2. SF Disposal Canister and Repository Layout](image)

The encapsulation plant (EP) has an annual production capacity of 40 copper canisters per year. Due to the small production capacity the operational period of EP is extended. In this revised concept, both the repository and the encapsulation plant are planned to operate 10 years in the variant 1 (estimated number of canisters is 389), and 15 years in variant 2 (571 canisters), after 1 year of trial operation. Planned repository operation starts in 2068 or in 2088 respectively, all activities and their durations are given in figure 1. At the end of operation, encapsulation plant will be dismantled and its contaminated parts processed as radioactive waste, and disposed of in the same repository.

The dismantling of above ground facilities should be finished within five years. About 3,000 m³ of repository operational and decommissioning waste (mostly LILW, with some 5% of waste assessed to be LL/HLW) will be placed in the unused deep underground compartments (e.g. service area). Also, the NPP decommissioning HLW waste that was stored in 6 CASTOR containers [1] together with SF will be added.

### 2.2 TRIGA research reactor

TRIGA Mark II research reactor at the Jožef Stefan Institute (JSI) achieved first criticality in 1966. Since then it was extensively used for various applications, such as: isotope production, irradiation of various samples, training and education, verification and validation of nuclear data and computer codes, testing and development of experimental equipment used for core physics tests at the NEK.
After reconstruction and upgrading in 1991, during which all core components with the exception of the graphite reflector around the core, were replaced with new ones, all the old fuel elements were removed from the core and replaced with the fresh fuel of the same type. That is standard TRIGA fuel containing 12 w/o of Uranium, which is 20 % enriched. Currently there are 84 fuel elements on reactor site, of which ~60 are in the core and the rest in the fresh fuel storage. In 1999 all the spent fuel was taken to the USA. Hence currently the only irradiated fuel is located in the reactor core and the fresh fuel storage pool is empty. On average 1 fuel element is used per year, meaning that with current fuel supplies the reactor can operate for at least 20 years.

Currently analyses of possible decision on future operation of TRIGA reactor after 2016 is going on. First the safety assessment of the reactor has to be performed in order to obtain answers about the technical feasibility to continue with operation and improvements needed. In case the operator will decide to continue with operation, the analyses of possible technical solutions for SF rods storage will need to be prepared. Basically there are 2 options: wet or dry storage, or both - one after another. Beside technical factors also costs will be important for the decision. If the decision on further TRIGA operation will be taken, all SF will be disposed in the final repository for SF from NEK after 2068 at earliest.

3 COST ESTIMATES FOR SF MANAGEMENT

3.1 Cost assessment of SF Dry Storage

For planning purposes it is assumed that the cost of storage building construction based on experience in constructing similar storage facilities is 30 million € (VAT excluded). The cost of CASTOR casks depends on the customer’s requirements and the number of casks. For the planning purposes the cost is estimated to 1,7 million € per cask.

The operational cost of storage consists of labor cost and cost of consumables (energy, water, maintenance). The cost of consumables was estimated to 624.000 €/year [1]. The total cost estimate for dry storage of SF according to time schedule in €-2009 is presented in Table 1.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Variant 1 (in 000 €)</th>
<th>Variant 2 (in 000 €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning and licensing of Dry Storage</td>
<td>4.000</td>
<td>4.000</td>
</tr>
<tr>
<td>Construction</td>
<td>30.000</td>
<td>30.000</td>
</tr>
<tr>
<td>Commissioning</td>
<td>166</td>
<td>166</td>
</tr>
<tr>
<td>Purchase of CASTOR casks</td>
<td>139.400</td>
<td>205.700</td>
</tr>
<tr>
<td>Packaging and transport to Dry storage</td>
<td>688</td>
<td>978</td>
</tr>
<tr>
<td>Operation</td>
<td>53.075</td>
<td>57.900</td>
</tr>
<tr>
<td>Renewal of license</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Decommissioning</td>
<td>3.000</td>
<td>3.000</td>
</tr>
<tr>
<td><strong>Total storage cost (no VAT, no contingency)</strong></td>
<td><strong>231.329</strong></td>
<td><strong>302.744</strong></td>
</tr>
<tr>
<td><strong>Total cost with contingency (15 %)</strong></td>
<td><strong>266.028</strong></td>
<td><strong>348.156</strong></td>
</tr>
<tr>
<td><strong>Total storage cost</strong></td>
<td><strong>319.234</strong></td>
<td><strong>417.787</strong></td>
</tr>
</tbody>
</table>

Compensations to local community for the SF storage is not included. The current legislation does not anticipate any financial compensation for SF storage facility. The contingency is
estimated to 15%. Since the technology is well known and proven the main uncertainties rest with other aspects of the dry storage project: site selection and confirmation, licensing procedures, project design and implementation.

3.2 Cost Estimates of geological disposal

Cost estimates were prepared for the two main alternatives: Variant 1 and Variant 2, depending on NEK lifetime and including time schedule given in Figure 1.

Total costs of geological disposal were calculated in two steps. In the first step costs per activities were estimated without any contingencies added. In the second step contingency for technological uncertainties were added and then, by using Monte Carlo simulation, the project uncertainties and VAT were calculated and added to project costs. So the total costs of geological disposal consist of:

1. Nominal cost estimate (as per December 2008) without contingencies,
2. Technology and project related contingencies and
3. Value added tax (VAT).

The technological uncertainties are related to the data available or experience available for a particular task implementation. The project uncertainties are related to the unforeseen events during realization of the project task. Factors, used for assessing the technological and project uncertainties are specified in [3]. Total contingencies increase net-net costs by 58%.

The costs are shown in Table 2 in €-2009. Purchase of copper canisters is included in the operating cost of the encapsulation plant. Similarly is the backfilling of boreholes as well as backfilling and plugging of disposal tunnels part of the repository operating costs. Under decommissioning and closure only the cost of backfilling of underground area is considered. For transportation costs 150 km distance between the repository and the storage has been assumed. Cost estimate of compensation to local community for limited land use is based on the Slovenian Ordinance [4]. The yearly sum of compensation during preparation period is 0.5 mio € and during construction, operation and decommissioning period 5.7 mio €.

Table 2. Cost estimates of Geological Disposal for Variant 1 and Variant 2

<table>
<thead>
<tr>
<th>Activity/facility</th>
<th>Variant 1 Cost (in million €)</th>
<th>Variant 2 Cost (in million €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siting and off-site infrastructure</td>
<td>145.970</td>
<td>160.212</td>
</tr>
<tr>
<td>Siting and site investigations</td>
<td>143.720</td>
<td>157.962</td>
</tr>
<tr>
<td>Off-site infrastructure and equipment</td>
<td>2.250</td>
<td>2.250</td>
</tr>
<tr>
<td><strong>Investment (Design &amp; Construction)</strong></td>
<td><strong>165.871</strong></td>
<td><strong>174.542</strong></td>
</tr>
<tr>
<td>Encapsulation plant</td>
<td>32.160</td>
<td>32.160</td>
</tr>
<tr>
<td>Surface facilities &amp; equipment</td>
<td>51.033</td>
<td>51.033</td>
</tr>
<tr>
<td>Underground facilities &amp; equipment</td>
<td>82.678</td>
<td>91.349</td>
</tr>
<tr>
<td><strong>Operating costs</strong></td>
<td><strong>140.441</strong></td>
<td><strong>203.867</strong></td>
</tr>
<tr>
<td>Encapsulation plant (including copper canisters)</td>
<td>89.589</td>
<td>130.388</td>
</tr>
<tr>
<td>Repository</td>
<td>48.872</td>
<td>70.569</td>
</tr>
<tr>
<td>Transport</td>
<td>1.980</td>
<td>2.910</td>
</tr>
<tr>
<td><strong>Decommissioning &amp; backfilling</strong></td>
<td><strong>16.746</strong></td>
<td><strong>17.877</strong></td>
</tr>
<tr>
<td>Encapsulation plant</td>
<td>1.608</td>
<td>1.608</td>
</tr>
<tr>
<td>Repository</td>
<td>6.460</td>
<td>7.601</td>
</tr>
<tr>
<td>Backfilling</td>
<td>8.678</td>
<td>8.678</td>
</tr>
</tbody>
</table>
4 CONCLUSIONS

Recently in Slovenia quite a large improvement have been achieved regarding the spent fuel management liabilities. This is especially true for the SF from NEK due to needs for development of the new revision of Decommissioning Program, drafted in 2010, which includes also plans for technical solution for storage and disposal of SF. Based on comparison of different dry storage options for NPP Krško dry storage of spent fuel in CASTOR casks was selected as the most practical option. Although CASTORs are licensed only for 40-years it seems feasible that the license could be extended, if long-term monitoring and fuel surveillance program will confirm casks leak tightness. Due to relative low costs it is recommended to elaborate and assess in more details the vault type of storage facility (HABOG type) in the future as an alternative. It is also recommended to prepare more detailed analysis of the selected storage option with evaluation of all important technical details including the equipment and hot workshop, as well as site selection costs. For SF disposal two versions were elaborated including technical solutions and other decisions (siting and site characterization including underground testing facility, underground works, equipment, encapsulation plant,...) for all steps. Contingencies have been seriously addressed and more systematically estimated. VAT has been included according to legislation. However, further improvements with more details on technical solutions and more reliable cost estimates are required with the data acquisition on potential host formations in Slovenia and in Croatia, work for improvement of the disposal concept including safety analyses studies which influence the design.

The performed studies also identified additional challenges which have to be answered in order to be capable of prospered decision taking and planning. New development in future nuclear build and higher prices of uranium open again the question of direct disposal or reprocessing of SF. At the same time NEK is analyzing the issue of additional repacking of SF pool or introduction of dry SF storage even during the operation period. Since the decision are interdependent and influence on each other the proper procedure has to be defined by the state. One of possibilities is to prepare a new revision of strategy on long-term SF management. Within this also planning of solutions for SF TRIGA reactor could be included in which investigations of storage and disposal options for SF rods can be given.

REFERENCES