GENERIC REPOSITORY CONCEPT FOR RBMK-1500 SPENT NUCLEAR FUEL DISPOSAL IN CRYSTALLINE ROCKS IN LITHUANIA

P. POSKAS, A. BRAZAUSKAITE, E. NARKUNAS, A. SMAIZYS, A. SIRVYDAS

Nuclear Engineering Laboratory, Lithuanian Energy Institute
3 Breslaujos st. LT-4403Kaunas – Lithuania

ABSTRACT

During 2002-2005 investigations on possibilities to dispose of spent nuclear fuel (SNF) in Lithuania were performed with support of Swedish experts. Disposal concept for RBMK-1500 SNF in crystalline rocks in Lithuania is based on Swedish KBS-3 concept with SNF emplacement into the copper canister with cast iron insert. The bentonite and its mixture with crushed rock are also foreseen as buffer and backfill material.
In this paper modelling results on thermal, criticality and other important disposal characteristics for RBMK-1500 SNF fuel emplaced in copper canisters are presented. Based on thermal calculations, the distances between the canisters and between the tunnels were justified. Criticality calculations for the canister with fresh fuel with 2.8 % ^{235}U enrichment demonstrated that effective neutron multiplication factor k_{eff} values are less than allowable value of 0.95. Dose calculations have shown that total equivalent dose rate from the canister with 50 years stored RBMK-1500 SNF is rather high and is defined mainly by the γ radiation.

1. Introduction

There is only one nuclear power plant in Lithuania - the Ignalina NPP. After final shutdown of INPP Unit 1 in 2004 and Unit 2 in 2009 total amount of spent nuclear fuel (SNF) will be approximately 22 thousands of fuel assemblies. All these assemblies should be stored about 50 years and after that disposed of. The capacity of existing SNF dry storage facility at the Ignalina NPP is for 80 casks. New interim dry storage facility that will accommodate remaining SNF is under implementation.

International consensus exists that spent nuclear fuel (SNF) and long-lived high level radioactive wastes are best disposed of in geological repositories using a system of engineered and natural barriers. During 2002-2005 the assessment of possibilities for disposal of SNF in Lithuania was performed with the support of Swedish experts. Extended studies on selecting of suitable geological formation had led to the conclusion that crystalline rock and argillaceous rocks are the primary candidates for disposal of SNF and long-lived intermediate level waste (ILW) in Lithuania [1]. In Lithuania, a crystalline basement occurs at depth of 200-2300 meters below the land surface. The prospective area of crystalline basement was confirmed as occurring in the southern Lithuania with the depths ranging from 210 m to 700 m, while in most of the Lithuania territory, the depth of the basement exceeds 700 m, reaching 2300 m in the west [1].

A generic repository concept for RBMK-1500 SNF disposal in crystalline rocks in Lithuania developed during mentioned studies is presented in this paper. Modelling results on thermal, criticality and other important disposal characteristics for RBMK-1500 SNF fuel emplaced in copper canisters performed using computer code FLUENT for thermal calculations, and code system SCALE 4.3 for criticality and doses calculations, also are presented in this paper.

2. Repository concept

The repository concept for SNF disposal of in the crystalline rocks in Lithuania is based on the repository concept developed in Sweden for SNF disposal of in the crystalline rocks (KBS-3). According to this concept SNF is emplaced in the copper canister with cast iron insert. Disposal canister and bentonite buffer of 0.35 m thick surrounding it are vertically emplaced in the crystalline rocks at the depth of 500 m. This disposal method is known as KBS-3V. At the present vertical and horizontal SNF canister disposal are under investigations by SKB (Sweden) and POSIVA (Finland) [2]. The advantage of KBS-3H compared to the reference design (KBS-3V) is that the deposition tunnels are not needed in that design. The absence of deposition tunnels reduces the excavated rock volume by about 50 %. This results to less environmental impact during construction, cost savings and reduced need for ventilation and drainage during construction and later on operation.

The main engineered barriers of the geological repository are waste form, waste overpack (canister), buffer and backfill materials for backfilling of the void space between the canisters and host rock. The container is one of the most important component of the multibarrier system. Two conceptual approaches are possible: corrosion allowance and corrosion resistance. The first involves the use of readily corrodible metals (e.g. mild steel and cast iron) with sufficient thickness to delay container failure for some thousands of years, i. e. until the short lived fission products in the wastes have decayed. The second involves the uses of corrosion resistant materials (e.g. copper or titanium alloys) that are intended to prevent water access for much longer periods (up to 100 000 years), possibly even until all the most mobile radionuclides have decayed and the waste hazard has declined to levels similar to those of natural uranium ore [3]. For SNF disposal of in the crystalline rocks the preference is often given to the copper canisters. Under the reducing water condition as it usually prevails in deep crystalline rocks the copper has very high corrosion resistance. Based on KBS-3 concept SNF disposal canister will be composed of two components: an outer corrosion protection of copper and a cast iron insert with channels for the fuel half-assemblies in order to improve the mechanical strength. The wall thickness of the copper canister is 50 mm and minimum wall thickness of the cast iron is 50 mm. Taking into account the results of the criticality, dose rate assessment and thermal calculations presented in the next chapters as well as taking into account the existing experience in the canisters shifting and emplacement technology it was proposed to load 32 half-assemblies of RBMK-1500 SNF in one disposal canister. Based on preliminary assessment the reference canister would be of 1050 mm diameter and 4070 mm length. For Lithuanian SNF disposal purposes about 1400 canisters should be employed.

Detailed repository design is clearly highly specific to waste type and to geological environment, but there are some general principles in it's design. Due to already mentioned advantages KBS-3H could be proposed as a reference as a reference design for Lithuania. As KBS-3H design is under the development in Sweden and Finland yet, thus KBS-3V is left as an alternative one, if KBS-3H is shown as not feasible and safe. There is no decision yet if the long-lived ILW will be disposed of in the same repository as the SNF or separately. In case of the first alternative possible layout of the repository is presented in Fig. 1. The main elements of repository are:

- an access shaft, transport tunnels, central waste receiving facilities and a shaft;
- an array of SF emplacement tunnels (deposition drifts);
- emplacement tunnels for long-lived ILW.

The waste emplacement tunnels, main tunnels and the transport tunnels would be excavated at a depth of 300-500 m in the crystalline basement. The SNF canisters would be disposed of at 1.2 m distance from each other in horizontally bored emplacement tunnels using so called supercontainer concept [3]. According to this concept each container with its surrounding bentonite buffer and a perforated steel shell (supercontainer) is placed between two compacted bentonite distance blocks in the emplacement tunnel [3]. The length of 250 m of SNF emplacement tunnels is accepted at this stage of investigations. The diameter of the SNF emplacement tunnel is proposed to be 1.85 m like in Sweden. The centre to centre distance between the emplacement tunnels is about 40 m. The length of shafts is dependent on the repository layout and selected site. Taking into account the distance between the SNF canisters and emplacement tunnels as well as the number of canisters to be disposed of, the deposition area for SNF will cover approximately 0.4 km^2 area.

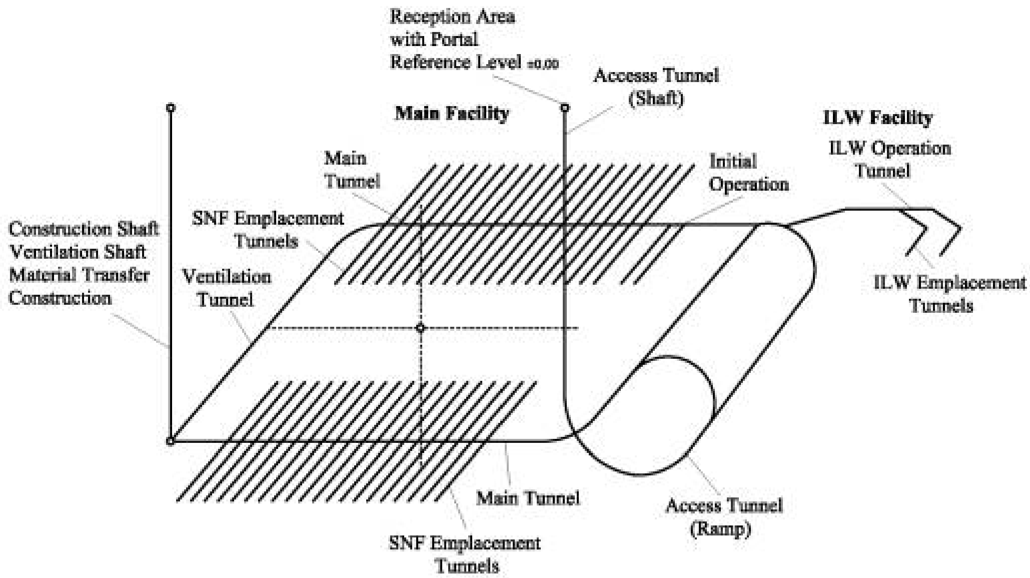

Fig. 1. Plan view of the repository for RBMK-1500 SNF disposal of in crystalline rocks

3. Performance assessment

3.1 Dose rate

Dose rate values will be important when spent nuclear fuel after interim dry storage will be emplaced in canisters and transferred to the repository. Calculated dose rate level indicates what measures should be introduced (for example, remote handling, additional shielding) to meet radiation safety requirements. The γ dose rate outside the canister is of importance for radiolytic disintegration of water also. The canister design criteria require that the γ dose rate not exceed 1 Gy/h (1 Sv/h if only β, γ radiation) in order to minimize the importance of the process [4].

Sequences SAS2H and SAS4 from SCALE 4.3 computer code were used for dose rate assessment of the canister with RBMK-1500 SNF. The main assumptions for the modelling of fuel assembly irradiation were following:

- RBMK-1500 fuel assembly that consists of 18 fuel rods was homogenized and in the reactor's fuel channel was described as an element of 5 concentric cylinders;
- Fuel enrichment 2.8% ^{235}U, burn-up 30 MWd/kgU, irradiation time 3 years, cooling time 50 years;
- For dose rate calculations axial burn-up distribution of fuel assembly was not taken into account.

Neutron and gamma radiation forms the total equivalent dose rate and from the canister with 50 years stored RBMK-1500 SNF the total equivalent dose rate is app. 500 mSv/h (Fig. 2).

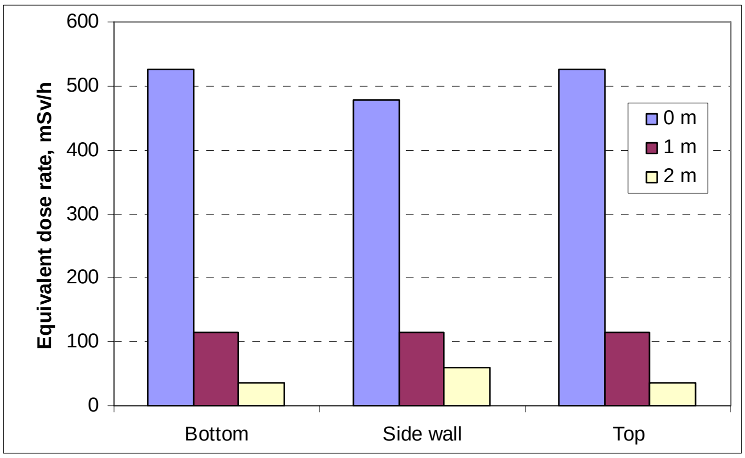

Fig. 2. Total equivalent dose rate values on the copper canister surface and at some distances

The results of dose rate calculations show that total equivalent dose rate is formed mainly by the γ radiation (more than 99.9%); neutrons forms only insignificant part of total dose rate. Dose rate calculations have shown that dose rate values on the surface of the copper disposal canister with RBMK-1500 SNF are rather high in comparison to SNF storage casks, but do not exceed the limit of 1 Sv/h which is maximum allowable dose rate value according to Swedish KBS-3 concept.

3.2 Criticality

Neutrons with suitable energy can cause nuclear fission particularly in ^{235}U, ^{239}Pu and ^{241}Pu in the SNF. Intruding water into the damaged canister can slow down the neutrons to suitable energies. A criticality conditions are assessed with the effective multiplication constant k_{eff}. Criticality analysis for copper disposal canister loaded with (2.8% ^{235}U enrichment) fresh 32 RBMK-1500 fuel half-assemblies was performed using SCALE 4.3 computer codes system. The following main conditions and assumptions were accepted for the criticality calculations:

- Maximum loading of the canister, i.e. insert of the canister contains 32 cylindrical holes each with fuel half-assembly inside;
- Discrete representation of the fuel rods is used in the geometry description. This means that each half-assembly consists of 18 fuel rods;
- The fuel half-assemblies contain only fresh, undepleted fuel (no credit for burnup) with 2.8% ^{235}U enrichment;

The variation of effective neutron multiplication factor k_{eff} (including 3 standard deviations) with water density for copper disposal canister shows that k_{eff} values continuously increasing when water density is increasing and maximal k_{eff} value of approximately 0.61 is reached when water density is 1.0 g/cm^3. The main requirement of the criticality safety is that effective neutron multiplication of the system containing fissile material must be less than 0.95. For copper disposal canister when long-term processes (corrosion, degradation, etc.) are not taken into account, k_{eff} values are less than allowable value of 0.95.

3.3 Thermal calculations

Temperature evolution calculations were based on the decay heat of the SNF, thermal and geometrical data of all parts of the repository. Temperature evolution in SNF tunnels was calculated using FLUENT 6.1 code.

Two cases were analyzed in total assuming that the buffer is partly saturated (low thermal conductivity) and fully saturated (high thermal conductivity) by water uptake from the surrounding rock. The results of time-dependant temperature evolution in the tunnel with horizontally emplaced SNF canisters show that, for the partly saturated (low thermal conductivity) bentonite, the peak temperature of ≈ 92 °C (Fig. 3, curve 1) on copper canister surface is reached within few years. In case of fully saturated (high thermal conductivity) bentonite the temperatures are much lower than in the case before. The highest temperature of ≈ 72 °C (Fig. 3, curve 2) on the canister surface is reached within 30 years.

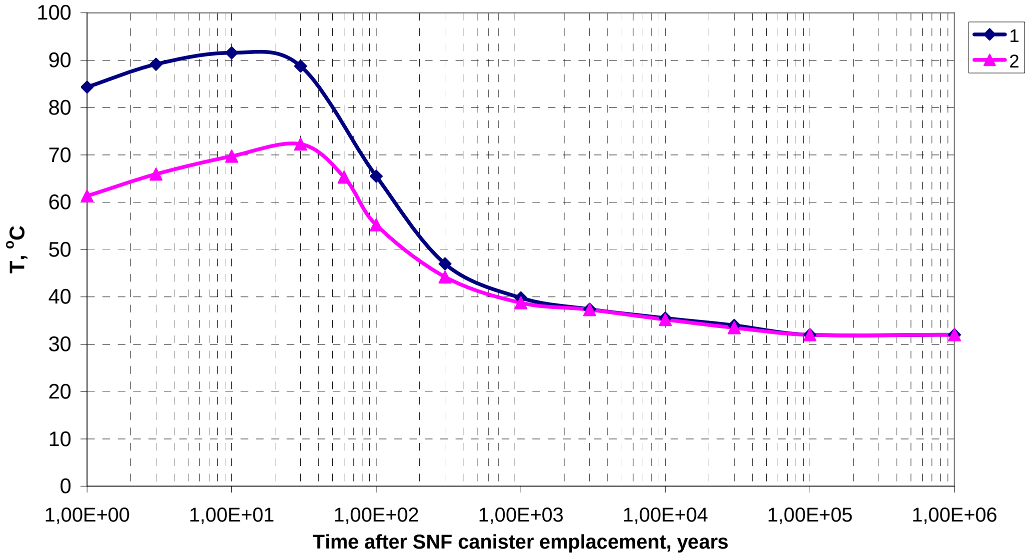

Fig. 3. Time-dependant temperature evolution on the surface of the SNF disposal canister in case of partly (1) and fully saturated (2) bentonite

The requirement that the surface temperature of the canister may not be exceed 100˚C [5] can always be met by choosing a suitable spacing between the canisters or by adjusting the fuel content in the canisters. The results of temperature assessment around the canisters loaded with 32 RBMK-1500 SNF half-assemblies show that a maximum heat output of 784 W per canister at the time of waste emplacement will satisfy the temperature constrain. Calculation results justify the chosen distance between canisters 1.2 m.

4. Summary

Generic repository concept for RBMK-1500 SNF disposal in the crystalline rocks in Lithuania was proposed based on Swedish KBS-3 taking into account the preliminary results on criticality, dose rate and thermal calculations of RBMK-1500 SNF.

5. Acknowledgement

Authors of this paper would like to acknowledge the support they have received from Patrik Sellin, Erik Lindgren (Swedish Nuclear Fuel and Waste Management Co) and Göran Bäckblom (CONROX, Sweden) in providing technical assistance and consultancy.

6. References

1. Investigations of possibilities to dispose of spent nuclear fuel in Lithuania: A model case. Volume 1. Suitability of geological environment in Lithuania for disposal of spent nuclear fuel, 2005, 66 p.
2. E. Thurner et al. KBS-3H – development of the horizontal disposal concept // Proc. of Int. Conference TopSeal 2006, Olkiluoto, 17-20 September 2006 (accepted for publication).
3. Scientific and Technical Basis for the Geological Disposal of Radioactive Waste. Technical Reports Series No. 413. Vienna: IAEA, 2003. 80 p.
4. Deep repository for spent nuclear fuel. SR 97 – Post-closure safety // SKB Technical Report TR-99-06. Vol. 1. 1999. 217 p.
5. What requirements does the KBS-3 repository make on the host rock? // SKB Technical report TR-00-12. 2000. 143 p.