MANAGEMENT OF DAMAGED SNF HANDLING OPERATIONS AT PAKS NPP

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Abstract

The issue of handling leaky fuel is one of the crucial issues of nuclear energy. It is directly connected with transportation of leaky spent nuclear fuel (SNF) that is mostly stored in the station's cooling pools. At present damaged spent nuclear fuel (SNF) of thirty VVER-440 spent fuel assemblies (SFA) is loaded into the ventilated canisters of types 28 and 29 and temporary stored in the cooling pool of Paks NPP. The report presents the milestones of preparation and safety justification of the technology for preparing canisters with damaged SNF of Paks NPP for transport to FSUE “PA “Mayak” (Russia) for reprocessing.

1. INTRODUCTION

On 10 April 2003, during the outage period a chemical cleaning program for the fuel assemblies was carried out at the unit 2, in a specially designed cleaning tank. The tank was located in a pit no. 1 near to the reactor. 30 fuel assemblies were significantly damaged due to inadequate cooling.

In the period of 01.10.2006–30.03.2007, the NPP and Russian specialists succeeded in arranging and performing activities to remove the content of the cleaning tank. All SNF (more than 5 tons) from the cleaning tank was loaded into the specially desined ventilated canisters of types 28 and 29 and it is temporary stored in the spent fuel cooling pool of Paks NPP.

Storage of SNF in the cooling pool in ventilated canisters filled with water requires development of the basic technology for subsequent handling.

Taking into account the state of the assemblies, the optimum solution would be to reprocess the spent fuel and dispose of the resulting waste.

In order to justify safety of management of damaged spent fuel, on behalf of Paks NPP Russian specialists have performed a significant amount of scientific research and design development work. The results became the basis for *the basic technology* for preparation of the canisters containing damaged spent fuel for transportation to Mayak for re-processing.

2. PREPARATIONS

The overall process of canisters management for transportation, shipment from Paks NPP to Mayak and further treatment provides for the following three key stages (shown on Figure 1):

- Handling of the canisters at Paks (preparation for shipment; removal of the canisters from the cooling pools);
- Transport of the canisters from Paks to Mayak;
- Re-processing of the fuel at Mayak.

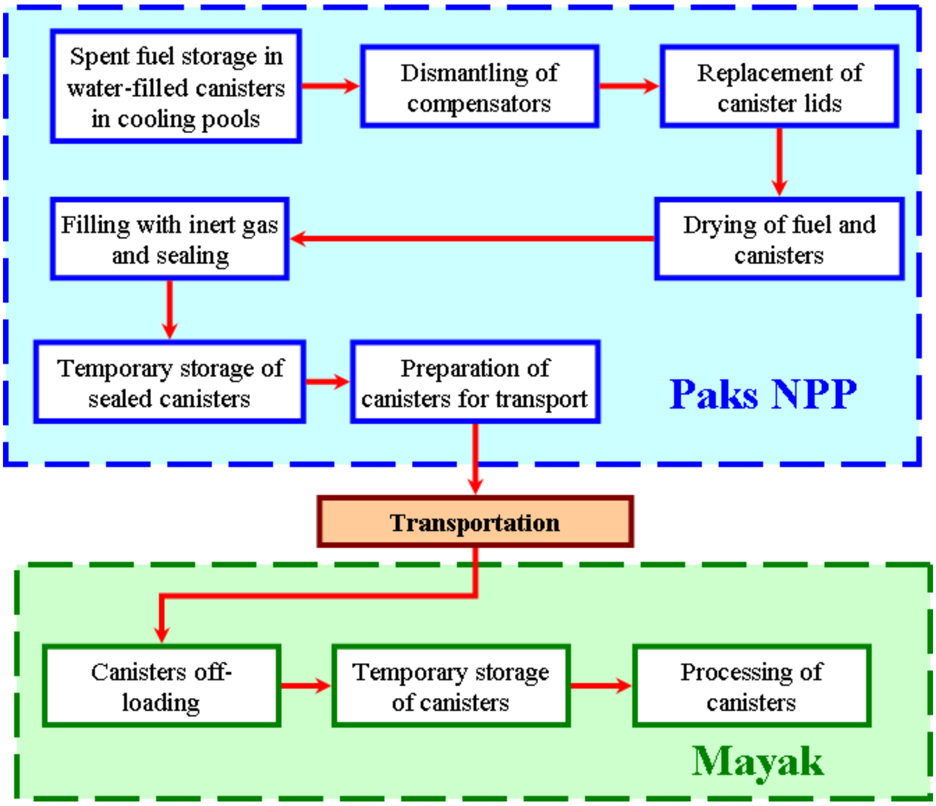

FIG. 1. Generalized schematic of canisters management.

The main difficulty with the assurance and justification of safety of transportation of wet damaged spent fuel is the need to keep the canister leak-tight over an extended period of time (to one year). This duration consists of the time the leak-tight canisters would be kept at the plant site, the time to deliver and receive to Mayak and the time the fuel will stay at Mayak before being actually cut up to be re-processed.

Transportation of wet damaged SNF differs from traditional way of handling intact SNF first of all due to presence of radiolysis of the residual water in the canisters. Radiolysis results in increase of pressure inside tight canisters and generation of explosive gaseous mixture. Based on the experience in handling damaged fuel at TMI-2 NPP it is one of the main processes influencing safety [1].

During the development of the basic technology, analysis was carried out of the Russian and international regulations, taking into account the safety requirements for management of damaged SFAs at the re-processing plant, and a justification was produced for transportation of failed spent fuel from the Paks site to Mayak. All key safety aspects of transport were considered: nuclear and radiation safety, structural integrity and leak-tightness of the canisters, thermal conditions, explosion and fire safety.

The preliminary calculations performed by the Russian Institute of Experimental Physics (VNIIEF) confirmed that defective spent fuel can be safely transported in gas-filled canisters types 28 and 29, the design of which takes into account the requirements of Mayak to handling prior to re-processing.

For the purposes of transportation, the transport overpack TUK-6 could be used with basket 13 (for type 28 canisters) and basket 12 (for 29 canisters). For loading of type 28 canisters into basket 13, additional transport inserts would have to be designed and fabricated. So that all canisters can be transported from Paks to Mayak, just four TUK-6 overpacks would be sufficient.

3. CHOICE OF CANISTER DRYING METHOD

Residual amount of water in the canisters must not exceed 5% of the mass of fuel; this requirement is attributable to the specifics of spent fuel re-processing at Mayak. Accordingly, water must be removed from the canisters before they are shipped to Mayak.

Preparation of canisters at Paks for transportation to reprocessing may be performed following these processes:

- Water removal with no additional drying, filling with an inert gas and sealing of the canisters;
- Water removal, drying of spent fuel, filling with an inert gas and sealing of the canisters;
- Drying of spent fuel without prior water drainage, filling with an inert gas and sealing of the canisters.

In order to select the optimum technology for preparation of the canisters for shipment, experimental equipment was designed and fabricated, and tests carried out to try the three approaches to water removal — on reduced-height simulators of type 29 canisters, loaded with irradiated VVER-440 fuel, and on full-scale type 28 and 29 canisters loaded with dummy spent fuel assemblies.

Electrotechnical casting porcelain (ECP) was selected to simulate damaged SNF. Thermophysical parameters of electrotechnical casting porcelain, UO_2 and ZrO_2, being important for drying, are provided in Table 1.

Heat capacity of the volume unit of ECP and UO_2 are close in values, i.e. the amount of heat required to heat ECP and UO_2, and consequently heating time are comparable. Thermal conductivity of ECP is 3 time less than thermal conductivity of irradiated UO_2 that gives an opportunity to simulate conservatively UO_2 drying using ECP. Simulators of fuel pellets were fabricated from ECP (Fig. 2).

TABLE 1. THE BASIC THERMOPHYSICAL PARAMETERS OF MATERIALS

No	Material	Density at 10% porosity, g/cm^3	Thermal conductivity at 0°C, W/m°C	Heat capacity at 20°C, G/kg°C	Heat capacity in 1 ml of volume, G/°C
1	UO_2 irradiated up to 30 MW·d/kg U	9,7	6	230	2.2
2	ZrO_2	5.2	2	502	2.6
3	ECP (SiO2~65%, Al_2O_3~24%, Fe_2O~0.6, TiO_2-0,5%, CaO-0.4%, Mg~0.3%, K_2O+Na_2O~3.5%, K_2O/Na_2O = 2-3.3)	2.3	2	900	2.1

FIG. 2. Simulators of fuel pellets from electro-technical casting porcelain.

Density of ECP is lower than the density of UO_2 and ZrO_2, i.e. particles of ECP of the same size are lighter than particles of ZrO_2 and UO_2. Therefore there will be more small particles carried out by the steam flow from the canister in the process of drying ECP than in the process of drying the full-scale canisters of types 28 and 29.

ECP was used also for simulating damaged ZrO_2, since thermal conductivity of ECP and ZrO_2 coincide and difference in heat capacity of the volume unit of these materials is not more than 20%. For conservative simulation of drying of “spillage” consisting of damaged pellets of UO_2 and oxidized fuel claddings, pellets from ECP were milled to the particle size less than 2,5 mm (Fig. 3).

To obtain grinded ZrO_2 standard unirradiated claddings of VVER-440 fuel rods fabricated from Zr-1%Nb alloy were oxidized in a muffle furnace at the temperature of 1000°C. After that they were crumbled as shown at Fig. 4.

FIG. 3. ECP with the particle size less than 2.5 mm.

FIG. 4. Grinded ZrO_2.

To determine the impact of the structural material oxidation extent on the drying speed simulators of cladding fragments with the bottom plugs of 300 mm long (Fig. 5) were fabricated from standard unirradiated claddings of VVER-440 fuel rods, half of the simulators was oxidized in a muffle furnace at the temperature of 1000°C (Fig. 6). Besides, the trimmed simulators of oxidized and non-oxidized fragments of the fuel rods beam were fabricated (Fig. 7).

FIG. 5. Simulators of non-oxidized fragments of fuel rod claddings.

FIG. 6. Simulators of oxidized fragments of fuel rod claddings.

Two types of SNF simulators used in the experiments for loading full-scale canister 28 are provided in Fig. 8. The first type is the full-scale beam of VVER-440 fuel rods, structural elements of which are not oxidized. Fuel rods represent the claddings (outer diameter of 9.1 mm, inner diameter of 7.72 mm) with the plugs at both ends and there is a throughout defect of 0.5 mm in diameter in the area of the upper plug. The claddings are filled with the simulators of the pellets from ECP (height of 10 mm, outer diameter of 7.6 мм, diameter of the central hole of 1.2 mm), the total height of the fuel column is 2420 mm. The second type is the fuel rods beam fragment of 1650 mm long, the structural elements of which are not oxidized. The fuel rods represent empty claddings with the plug at the bottom and removable part of type 6 of canister 28 of 850 mm high completely filled with particles of ECP of the size less than 2.5 mm.

a *b*

FIG.7. Trimmed simulators of oxidized (a) and non-oxidized (b) fragments of fuel rod beam.

FIG. 8. Simulators of SNF for canister 28.

After removal of water, some moisture will still remain in the canisters, and the process of radiolysis may cause pressure to rise above permissible, and a highly explosive mixture of hydrogen and oxygen may form. In order to determine the amount of residual moisture in the canister that would guarantee safety at all stages of management, experimental research was performed to model the storage of deteriorated spent fuel in a leak-tight canister, after water removal by various methods. Fuel from VVER-440 FA with the following parameters was used for experiments:

- Initial enrichment by U^{235} — 3.6%;
- Average burnup along FA — 27.6 MW·d/kgu;
- Maximum burnup along FA height — 32.0 MW·d/kgu;
- Total FA operation time — 649.1 eff.d;
- Date of discharge of FA from the reactor — 18.06.99.

Logical sequence of experiments is provided in Fig. 9. Level-one experiments determined the conservative with respect to radiolysis condition of spent fuel for all types of canister loading at Paks.

The testing rig to examine behavior of damaged VVER-440 fuel under conditions simulating SNF storage in tight canisters was created to perform level-two experiments.

Level-two experiments measured the rate of generated of hydrogen, oxygen and gaseous fission products into the canister cavity depending on the amount of residual water and ambient temperature. These results are conservative with regard to Paks NPP fuel loaded into canisters of types 28 and 29.

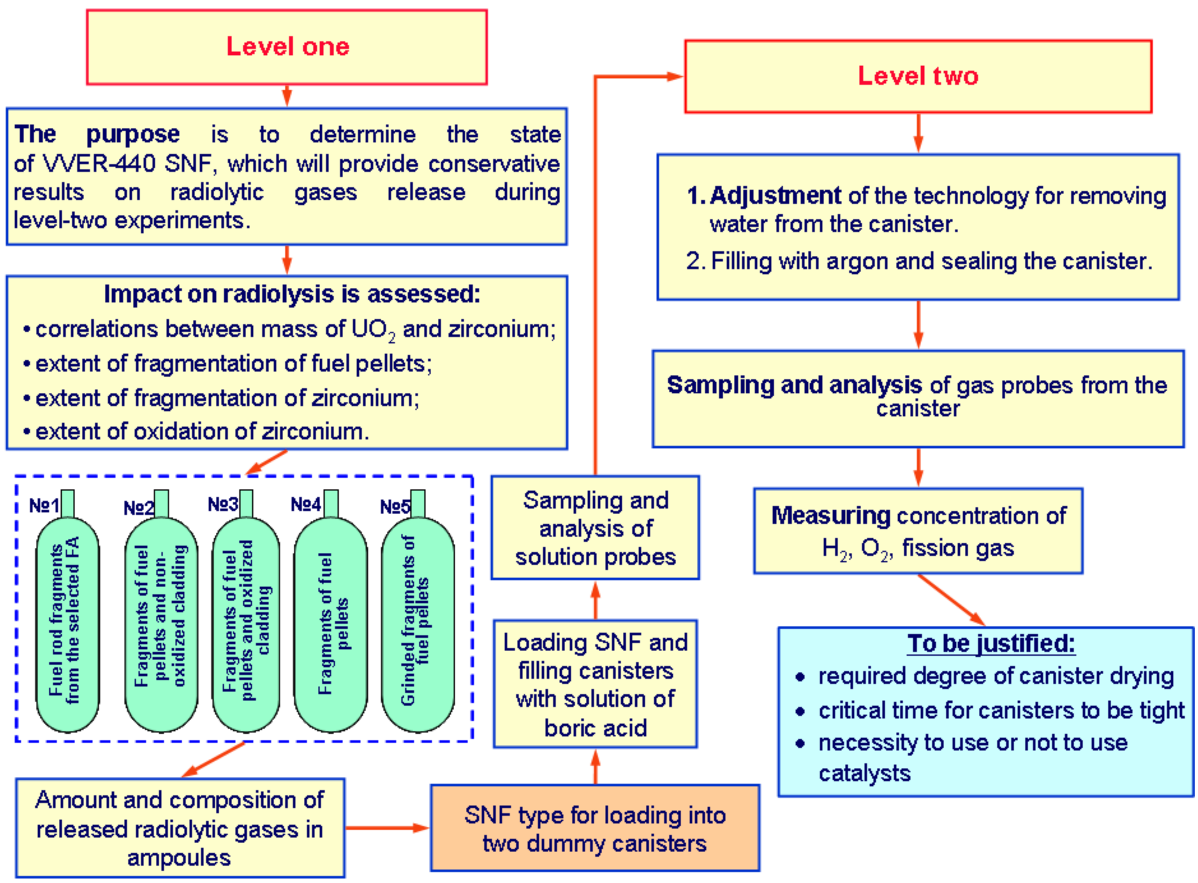

FIG. 9. Logical sequence of experiments.

Based on the results of the experiments the following conclusions were made:

- Justification of safety at all stages of management of canisters sealed after water drainage is impossible, as over six months volumetric concentration of hydrogen in a type 29 canister with free cavity volume 20 litres will reach 8.7%;
- If, however, after the end of thermo vacuum drying the residual pressure in the canister does not exceed 6 mbar, then after two years of storage in a leak-tight type 29 canister with free cavity volume 18 litres volumetric concentration of hydrogen will not be greater than 0.05%, whereas in a 28 canister with free cavity volume 50 litres it will not be higher than 0.04%;
- The amount of hydrogen that the canister would accumulate over twice as long in a leak-tight condition, would be two orders of magnitude below the level of self-ignition for the oxygen-hydrogen mixture;
- With leak-tightness class IV (permissible leakage up to $6.7 \cdot 10^{-7}$ $Pa \cdot m^3/s$), the time it will take for the excessive pressure in the canister to drop is many times greater than double the duration of time from the beginning of sealing of the first and completion of processing of the last canister;
- Since there is lack of oxygen in the canisters tightened after thermal vacuum drying, it is not efficient to install catalysts in them.

Taking into account the estimated duration and exposure, as well as the quantity of resulting radwaste, thermo vacuum drying without prior drainage was identified as the optimum approach.

Safety of canisters management prepared and sealed following this process and nuclear safety of the process of spent fuel accumulation on the filtering elements were confirmed by the experiments. It was determined that the release of gaseous fission products during drying the canisters would not exceed the reference level established at the Pask NPP. Dilution with air has been proposed for non-condensing gases as they are pumped from the canister to prevent formation of explosive mixes.

As a result of the research and development activities, experimental results and analytical evaluations have been obtained that are needed for licensing of the canister drying technology with no prior drainage of the boric acid solution.

4. BASIC TECHNOLOGY OF CANISTERS PREPARATION

The basic technology for preparation of the canisters with spent fuel for shipping to the re-processing facility ay Mayak shall ensure:

- Non-exceeding the dose limits for personnel exposure;
- Safe temporary storage of canisters with spent fuel in the cooling pools;
- Observance of the paks npp safe operation limits;
- Minimal release of nuclear materials and radioactive isotopes from the canisters;
- Minimisation of radwaste generation.

The technology should be based on the following provisions:

- For assurance of safe conditions of transport, the canisters with spent fuel must be dried, filled with an inert gas and sealed;

- Prior to drying, the current lids suitable for water-filled canisters must be replaced with lids suitable for gas-filled canisters; these activities are to be performed in pit №1;
- During storage and transport of dried gas-filled canisters, catalysts for oxidation of hydrogen are not used;
- Drying of the canisters is performed without prior drainage;
- Drying, filling with an inert gas and sealing of the canisters is performed inside a shielded technological module installed into pit k1;
- Before loading into the tuk, the gas-filled canisters are stored in the cooling pool;
- All movements of the canisters with spent fuel between the pool and pit k1 are performed by the re-fuelling machine;
- For the preparation of canisters for transport, existing equipment used for removal of spent fuel from the cleaning tank should be used to the maximum extent possible (it may be upgraded to accommodate the new tasks).

The technology is technically feasible, with a sufficient necessary level of safety assured. There are currently no major insurmountable technical or legal obstacles standing in the way of transporting the failed fuel canisters for re-processing to Russia.

Simulation of handling operations with type 28 and 29 canisters at Mayak demonstrated that they can be processed using the plant's standard technology. The equipment and technology of the plant are ready to receive and re-process the failed spent fuel from Paks NPP.

REFERENCES

[1] TRAVERS, W. D., NRC Staff safety evaluation in support of reduced canister void volume 71-9200 (1987).