SAFE DECOMMISSIONING OF MOBILE NUCLEAR POWER PLANT

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Abstract: The paper addresses some issues for ensuring radiation safety during the process of decommissioning the 630 kW "Pamir-630D" mobile nuclear power plant (MNPP). That nuclear power plant consisted of a gas cooled reactor (weight of 76.5t), gas turbine-driven set (76t), two control units (2×20t), and an auxiliary unit (20t). The reactor and turbine-driven set were supposed to be put on transport platforms and carried by tractors. The control and auxiliary units were set on track beds. The "Pamir-630D" was constructed and tested in an appropriate building. The set-up time was no greater than six hours after all units of the MNPP had reached the site. The "Pamir-630D" was ready to be moved to another site in 30 hours after the shut down. Service lifetime of "Pamir-630D" was 10 years: 7 years of storage and 3 years of operation. Operational lifetime was no less than 10000 hours (non-stop operational period was no longer than 2000 hours). Dose rate at the boundary of the restrictive area was no more than 6.5 mR/h at the time of reactor operation and no greater than 300 mR/h on the side surface and 1000 mR/h on the end surface of the biological shielding of the reactor, 24 hours after shut down.

Two pilot prototypes of the "Pamir-630D" were constructed. The first was put into operation in 1985. The second was not put into operation. The first prototype of reactor was in operational for 3668 hours.

The MNPP was shut down on 26 November 1987 the reactor was cooled by circulating a gas-liquid coolant in the main loop until 24 June 1998. After that time the reactor was cooled by a liquid coolant circulated through the auxiliary loop of the accident cooling system of the reactor. The coolant was removed from all circuits on 22 May 1988 and the reactor was filled with nitrogen and cooled until removing the fuel.

The reactor unit included: a vessel reactor cooled with "nitrin" gas based on N_2O_4, biological shielding, and pipelines with valves. The reactor vessel and other auxiliary equipment were made of stainless steel. The reactor core consisted of 106 fuel assemblies, each of them contained 7 fuel rods surrounded by stainless steel cladding with a wall thickness of 0.4mm and a diameter of 6.2mm. Fuel spherical particles of UO_2 enriched to 45% ^{235}U were embedded in a Ni-Cr matrix. The share of nickel and chrome in the fuel composition was 40%. Additional data are summarised in Table 1.

The reactor was surrounded by four layers of biological shielding:

- inner lead layer with a thickness of 100mm;
- boron carbide layer with a thickness of 100mm;
- lead layer with a thickness of 100mm; and
- outer borated polyethylene layer with a thickness of 620mm.

Annular clearances between layers were used as air ducts to cool the biological shielding.

Table 1 - Reactor data

Parameter	Value
Material of moderator and reflector	Zirconium hydride
Fuel	UO_2, enriched to 45% ^{235}U
Construction material	Stainless steel
Material of reactor control rods	Eu_2O_3
Burn up, %	14.3
Weight of ^{235}U in reactor core, kg.	18.7
Height of the reactor core, mm.	500
Diameter of the reactor core, mm.	506.7
Coolant	"nitrin" base on N_2O_4
Coolant flow rate, kg/s	5.68
Maximal temperature of, C^0:	
fuel rod cladding	700
moderator	570
fuel	1150
Coolant temperature, C^0:	
inlet of reactor	189.5
outlet of reactor	503
Weight of the reactor core, kg.	5700

The turbine-driven set consisted of the turbine, electricity generator and auxiliary equipment to maintain coolant quality in accordance with appropriate chemistry requirements. All parts of the turbine unit were made of stainless steel.

The decommissioning plan included a short period of preparation for disposal followed by the dismantlich of the reactor and turbine units and the safe long-term storage of spent fuel in an appropriate storage facility. All procedures for decommissioning were thoroughly prepared to protect the personnel against radiation and to meet the nuclear safety requirements. Special equipment was designed and constructed to unload the reactor core and to dismantle the reactor and turbine units. All persons involved in the decommissioning activities were made familiar with the "Pamir-630D" site and the safety procedures for the safe and effective performance of their duties.

Dismantling of the reactor unit was carried out after the following actions were accomplished:

- cooling core after shut down;
- mounting of unloaded fuel equipment;
- removal of spent fuel; and
- reactor cleaning (removal of remaining coolant).

A decommissioning plan was designed for each procedure. In the process of the fuel core unloading, the personnel were provided with individual dosimeters, including those in case of an emergency. The constant two-side connection between the reactor cavity and control room was set up. Radiation monitoring was ensured from the moment of unloading the fuel assembly till its loading into the flask.

In the process of unloading the active zone the personnel was provided with individual dosimeters, including those for emergencies. The constant two-side connection between the reactor cavity and control room was ensured. Radiation monitoring was ensured from the moment of unloading the cassette from the active zone until it was placed into the container. Within the reactor, core environment samples were constantly taken to identify presence of radioactive aerosols.

Personnel not involved in activities related to the unloading was not permitted to be present within the reactor core. During radioactive equipment dismantling, end-pieces were prepared and welded to coolant circuit piping.

The following measures contributed to the safety ensurance during nuclear fuel unloading, transportation and storing: proper organization of all activities, observance of the safety requirements, use of a protective system (EKRAW), use of transport containers and fuel storage of special design, and continuous radiation monitoring. When contamination was detected above pre-established limits, decontamination procedures were applied.

Average calculated occupational dose during the most dangerous operations from the safety point of view was approximately 140μSv/h. The dose rate 1 m from the biological shielding of the reactor did not exceed 14μSv/h, on the surface of the biological shielding it was not greater than 35μSv/h, and 180μSv/h at the lower part.

For the purposes of exposure calculation during active zone uploading activities values of each element of the reactor were estimated. Dose rates near the dismantled elements are shown in Table 2.

Table 2 – Dose rates from major components

Piece	Dose rate, μSv/h	
	At contact	At distance of 1m
Air duct	1.8	00.7
Vessel top plate	70	3.9
Nuts of vessel top plate	2	0.002
Studs of vessel top plate	100	0.2

Bottom of fuel assembly	$1.6x10^4$	300
Lead biological shielding	1.6	0.06
Boron carbide biological shielding	15	0.2

The reactor volume was filled with water that had a boracic acid concentration of 8g/l. The water quality was checked twice a week. Special equipment included a tank for temporary storage of radioactive pieces of the reactor, a turntable with biological shielding and a turntable with devices and a tank (height of 5.3m, a diameter of 2m) for removing the fuel assemblies. This apparatus was designed and constructed to unload the reactor core under water.

This equipment was installed instead of the six slabs which covered the reactor cavity. Dismantling of the nuts and the studs of the top plate of the reactor vessel was carried out using the turntable with the biological shielding made of lead which had a thickness of 150mm. Dismantled items were placed into the storage tank filled with water. The tank for unloading the spent fuel was set above the top plate of the reactor vessel after the removal of the turntable with the biological shielding. That tank was filled with borated water with height of 4370 mm to decrease the radiation exposure of the operating staff. After removal of the top plate of reactor vessel, the unloading of the reactor core was carried out in accordance with the core cartograme and residual thermal power of core was no more than 0.3 kW. The steel imitators were set in place when an assembly was removed. The gas tightness of the assemblies was checked under water and the intact assemblies placed in a tank. The fuel assemblies with cladding defects were placed in sealed cans and then placed in the flask. The flasks were moved to the temporary spent fuel storage area by the overhead travelling crane. The transportation of the flasks was carried out at a distance of 0.5 m above the floor, which was covered with polyethylene film to prevent contamination of the building.

The coolant was removed from all circuits and equipment of the turbine-driven set after the shut down. The loops of the unit were blown by air and washed by water. All pipelines between the reactor and the turbine units were disassembled and blanked off. The dismantling of the turbine unit equipment was carried out by cutting the pipes. The non-radioactive parts of the turbine unit were recycled or used for other purposes. The following radioactive equipment of the turbine-driven set was dismantled and removed for the disposal in the concrete vaults: condenser, pumps, tanks, pipelines, valves, tranducers of the I&C Systems for the main loop and auxiliary systems, and the turbine.

The non-radioactive parts of the reactor unit were recycled or used for other purposes. Dismantled radioactive pipelines were blanked off and welded. The following radioactive pieces of the reactor unit were disposed at the burial site: pipelines with valves of main and auxiliary coolant circuits, heat exchangers, condenser, and air duct of biological shield. All dismantled pieces were packed in polyethylene film and carried to the storage for the disposal in the concrete vaults. The reactor vessel with its biological shielding was disposed in the concrete vaults without dismantling. The dose rate (γ-ray) at a distance of 1m from the surface of the concrete cover was no more than 28μSv/h.

Other material, equipment and parts of the MNPP with significant activity despite of the decontamination, were removed for disposal.

The temporary storage facility with the water shielding (thickness of 3.1 m) and concrete shielding (thickness of 1.8 m) was built near the reactor cavity. The spent fuel assemblies are kept under water in two pools (volume of 2×28 m^3). The water quality is maintained in accordance with appropriate chemistry requirements. The flasks with the fuel assemblies are tested for leak tightness. This is done by weighing the containers under water. If the weight is stable, this check is done quarterly. If there have been changes in the weight, the container is checked weekly. The flask is removed for testing and the leak tightness is corrected in a hot cell in accordance with appropriate procedure if the reference weight increases by 100 g.

The reprocessing technology for this kind of the nuclear fuel has not been developed. Taking into account this fuel has been designed only for the "Pamir-630D" and has not been used in any other type of reactor, its technology of reprocessing perhaps will not be elaborated in near future, so it is necessary to provide with long-term safe storage of the spent fuel.

After decontamination it is possible to permit unrestricted use of parts of the nuclear power plant building while others (fuel storage facility) are still subject to restrictions. Surveillance, monitoring and inspections are carried out to ensure the spent fuel storage remains in good condition. The non-radioactive parts of building are used for new purposes. A subcritical assembly with neutron generator, an electron accelerator, and a γ-ray facility has been in the building before it was used for the "Pamir-630D" operations.