CHARACTERIZATION AND REMOVAL THE SLUDGE AND DEPOSITS

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1. INTRODUCTION

1.1 NPP A-1 description

Basic characteristics

The NPP A-1 with heterogeneous reactor based on thermal neutrons was designed for gross electric output 143 MWₑ. Natural metallic uranium had been used as a fuel, heavy water served as moderator and carbon dioxide was used as cooling medium.

The primary cooling circuit consists of six loops and each loop comprises one steam generator, turbo-compressor and two parallel piping of hot and cold cooling legs. Three cooling circuits, each comprising two coolers and one heavy water pump, provided cooling of the moderator.

Independent part of the NPP A-1 were facilities for assembling of fuel assemblies and the facilities of the transport-technological part which had served for fresh and spent fuel handling, cooling down and storage.

Three turbo-generators, each installed output 50 MW, were the main parts of the secondary circuit.

Short history

Construction of the NPP started in 1958 and the first controlled reactor power was reached in 1972. A-1 was constructed as an experimental demonstration plant and all main components had a character of prototype. In spite of this, the NPP was included into the power system with determined plan of electrical power production and operated for 5 years with several breaks. Two serious accidents happened during the operation. After the second accident in 1977 (INES level 4), the NPP was definitively shut down.

Both accidents led to the damage of several fuel assemblies with extensive local damage of fuel cladding. As a consequence primary circuit surface (steam generators represent the main part) was significantly contaminated by fission products and long lived alpha nuclides.

During second accident, heavy water circuit was also contaminated – the evaporator surface of moderator polishing system represents the main remaining contamination. The leakage of moderator and coolant mixture contaminated by fission products through corroded steam generator tubes resulted in the low contamination of the secondary circuit.

Restoring NPP operation meant repairing the reactor, replacing the steam generators and some other damaged and unreliable facilities and systems. Technical-economical assessment of the requirements showed that it was not effective to perform such extensive and expensive modifications and refurbishment so the NPP A-1 entered the decommissioning phase in 1979.
Current state

In 1992, the Slovak government adopted the concept and time schedule of NPP A-1 decommissioning but only in 1999, the licence for the first phase of decommissioning was issued. The decommissioning project is currently going on and planned to be finished by 2049. The objective of the first phase to be completed by the year 2007 is to reach the radiological safe state without spent fuel and without uncontrollable release of radioactivity into environment. Decontamination of primary circuit installations, auxiliary loops and other heavily contaminated objects of the facility is the task of top priority.

Due to very high dose rate fields and surface contamination with high contents of alpha radionuclides, the process of decontamination and decommissioning of the nuclear power plant A-1 is very complicated, slow and expensive

1.2 General strategy for realisation of partial decontamination tasks

The tasks in the NPP A-1 decontamination are mostly non-routine and non-standard activities. The first step in the decontamination of all objects is the thorough mapping of the radiation situation and investigation of the type and character of the radioactive waste. Measurements of dose rates in rooms with technological equipment to be decommissioned are taken at horizontal steps 0.5x0.5 m at different vertical levels at each step. Models for the distribution of the intensity of radiation fields are developed based on values of dose rates. The main sources of the radiation are identified and localized. Remote controlled mechanical manipulators and remote controlled electrical carriages equipped with instruments recording levels of dose rates and with telemetric data transmission system are used for the monitoring in high radiation fields.

Radiation monitoring is completed with non-fixed surface activity measurements, sludge and deposits sampling and analysing.

Inside and outside inspection and TV-camera monitoring of equipment are also very important and frequently used. The actual state is compared with the appropriate design documentation and based on these data the 3D visualisation of touched rooms and installed technological equipment is prepared. Very good results in the safety and effective dismantlement have been achieved by 3-D visualisation of treated facilities, calculation of cutting velocities and by detailed portioning of cut materials for each shift and each cutting team.

The schedule of work procedures are analysed based on the actual situation in rooms and, given the aim and criteria, the best work procedures are chosen. The work procedures are split into several phases, tasks and subtasks, depending on the planned operations. The collective dose equivalent and the maximum individual dose equivalent are calculated on the basis of the distribution model of the dose rates at the work place using the software tool ALPLANNER.

The application of the ALARA principle and the optimisation of radioprotection have got an impact on the organization of the works. A great part of activities is moved into preparation phase. The non-active testing of the principal operation on actual size mock-ups, applied before the realisation phase, is very worthwhile economically as well as for training of staff.
and radioprotection purposes. This principle of non-active testing and training of staff is also applied for auxiliary tasks, like for instance the transport of highly radioactive wastes.

The minimisation of the secondary radioactive waste production is also taken into consideration. The selection of the appropriate decontamination method that produce low amounts of radioactive waste is of the high priority together with an adequate time spent on the development of the decontamination equipment and the preparation and training of the staff.

Decontamination works start after approval of the Work Program. During works, data important from point of view of radiological protection and ALARA are collected, evaluated and recorded. These data are evaluated and lesson learned are given in the final Work Program evaluation.

2. EXAMPLES AND EXPERIENCE

2.1 NPP A-1 hot cell decontamination

During the NPP A-1 operation, the hot cell served for the realisation of some remotely operated procedures with higher active subjects (spent fuel elements disassembly, sampling of the metal subjects, manipulations with casings containing radioisotopes, etc.). Fine solid particles were released from the treated subjects throughout these operations and, subsequently, the surface and the installed equipment of the hot cell were heavily contaminated.

The radiation monitoring showed dose rates from 5 to 200 mGy.h⁻¹ and surface contamination up to 10 MBq.cm⁻² (on the floor). The ratio of $^{137}$Cs : transuranic radionuclides (Am, Pu) ranged from 100 : 1 up to 2 : 1 in non-fixed contamination.

The decontamination of the hot cell is realised in the first half of the year 2004. In respect of the radiation situation, the entrance of realisation personnel into this room is impossible. Therefore, the using of the remotely operated manipulator to perform the decontamination is necessary. The design of the manipulator enables the establishment of the manipulator into the hot cell through the opening in the shielding ceiling and reaching of all decontaminated surfaces. The method of high pressure water jetting in the combination with decontamination gels was selected for the decontamination. The application jets are installed on the manipulation arm end. TV monitoring system consisting of three cameras is a part of remotely operated manipulator and using this system the operators control the manipulator and perform the particular operations being on the control viewpoint.

The selected working procedures ensure the minimisation of external and internal occupational doses. The thorough preparation phase was foregoing to the realisation of decontamination. This preparation phase consisted of the tests and optimisation of the designed decontamination equipment and procedure using the mock-up model of hot cell in the scale 1:1 (Figure 1). Operators used the mock-up model for the training of the working procedures, too.
2.2 Decontamination of the tanks at the NPP A-1

In the collecting and manipulating tanks for liquid radwaste the non-soluble sludge gradually occurs and settles on the bottom of them. Due to its stickiness, thixotropy and high sedimentation relatively high amount of sludge is entrapped in these tanks even if the drainage pipe is installed on the bottom of the tank. Most of activity is cumulated in the sludge.

The management of the radioactive sludge presents a serious problem because of:

- very high specific activity of sludge (from $10^8$ to $10^9$ Bq kg$^{-1}$ gamma, alpha activity is usually by three or two orders lower, beta activity by two or one order lower depending on the source of sludge)
- unfavourable properties from point of manipulation, such as stickiness, thixotropy, non-homogeneity, high sedimentation, content of dry matter of 20 to 50 % (mass).

The removal of sludge from tanks belongs to the more difficult operations. There are two basic approaches to removing sludge waste from tanks:

- mix or suspend waste in a liquid so that slurry can flow to a fixed location where a pump then removes it from the tank (in the case of small objects, if there is any trap)
- remove waste using a movable tool operating at the waste surface.

Several collecting and manipulating tanks have been decontaminated at NPP A-1 (collecting and manipulating tanks of carbon steel and stainless steel special drainage system, neutralisation tank, sedimentation tank, etc.). Typically, they are the horizontally mounted cylindrical tanks with the diameter of 1200 – 1500 mm, length of 2300 – 4500 mm and inner volume of 2,6 – 6 m³.

The realisation of decontamination of these objects was very difficult and complicated because of very high radiation fields around them. The dose rates in the contact with these tanks reached values up to 150 mGy h$^{-1}$. So the very first step was the building of shielding wall in front of these tanks which consisted of modules filled by metal grains.

An ejector pump is used to remove the sludge from tanks. The suction pressure in the ejector is obtained by high-pressure water. The suction hose tail is placed at the bottom, and the end of the discharge hose is fixed in a collecting drum. The suction hose tail of ejector pump is
moved around the bottom with the help of a simple manipulator and the sludge is continually pumped into 60 dm³ drums outside room and then the sludge is prepared for the solidification into the SIAL matrix directly in those drums.

The fixed contamination and deposits on the inner surface of the collecting tanks is removed by the high-pressure water jetting or by a chemical loop decontamination method using a simple circulating decontamination device. With regard to secondary radioactive waste minimisation, the collecting tank is not completely filled up by the decontamination solution. Just a minimal amount of the decontamination solution is used and this solution is uniformly sprayed on the surface of the tank and the decontamination solution is collected on the bottom of the tank and fluently recirculated using a pump. The decontamination solution is sprayed with a system of variable oriented jets on a rotating head that rotated due to the action of the liquid flowing through the jets (Figure 2).

![Figure 2. Inner surfaces of the collecting tank before and after decontamination](image)

2.3 Decontamination of the rooms at the NPP A-1

Due to leakages of high active mediums from the technological equipment the high level contamination occurred also on the infrastructures and external surfaces of equipment. For example, in 1991 during the fitting of non-manipulating spent fuel elements before their transport to a reprocessing plant approximately 100 dm³ of the high-active cooling medium (chrompik) leaked out on the floor of the reactor hall and, subsequently, into the rooms bellow the hall and caused a large-scale contamination of the building surfaces, equipment and subjects situated there. Occurred radiation situation in these rooms (40 – 400 mGy.hod⁻¹) did not permit the entrance of the personnel. The initial monitoring, clearing and decontamination of the affected surfaces had to be done using remotely operated manipulators checked by the TV cameras.

Due to the absence of management of secondary radioactive waste at the NPP A-1 in the foregoing periods, there were different subjects and parts of dismantled equipment stored without restraints in these rooms and these subjects were also highly contaminated by leaked medium.

The remotely operated device with the jointed manipulator was used for the removal of objects stored in the room No. 459 before its decontamination. The objects were step-by-step removed out of room and restored into the transportable container. The control centre was
established on the place with minimal radiation intensity. From this point the operators controlled the mobile device and jointed manipulator by means of control components and wireless transmission of picture. The removal of objects was realised during 20 working shifts (4 hour net working time) and about 120 items were removed from the room. The occupational dose of operators was minimal.

After the removal of the objects, usually the floor remained the most contaminated part of the room. Another remotely operated device DOV-Deco with replaceable decontamination extension heads was used for the decontamination of the floor (Figure 3).

DOV-Deco is remotely operated carriage. Owing to the four-wheel drive, the carriage moves forward, backwards, on the left as well on the right. The carriage is connected with a control unit through an electrical cable. A TV-camera is installed on the carriage and its signal is fed to a monitor on the control unit.

For the decontamination of larger horizontal areas covered by a washable paint the carriage is equipped with a decontamination tool that combines two jobs in one operation – efficient cleaning using high pressure water together with controlled removal of spent water and loosened contamination by vacuum. The high pressure systems uses high energy water jets at flow rates of up to $16 \text{ dm}^3 \cdot \text{min}^{-1}$ and pressure up to 250 bars. The removed contamination and used water is suctioned by vacuum unit and is trapped in collecting drum that is integrated into the suction way, between the decontamination tool and vacuum unit. Suction and suction seal design ensures no escape of water during the right operation.

In the case the floor is made of concrete in which the contamination is penetrated, DOV-Deco with a grinding extension along with an exhaustion system is used for the decontamination. Similarly, the removed contaminated concrete is suctioned by vacuum unit and is trapped in collecting drum with a cyclone that is integrated into the suction way, between the decontamination tool and vacuum unit with HEPA filter.

After repeated decontamination of the floor with DOV-Deco the non-fixed contamination on the floor dropped under $3.0 \text{ Bq.cm}^{-2}$ from the original values of $10^6 \text{ Bq.cm}^{-2}$.

Figure 3. Remotely operated carriage DOV-Deco with different decontamination extension heads
2.4 Monitoring and sampling of the capacious collecting tanks at NPP Dukovany

In 2003, a large-scale program for the TV and radiation monitoring and representative sampling of four capacious tanks TW at the NPP Dukovany (Czech Republic) was prepared and realised. There are sludge, ion exchangers and different others deposits settled in the cylindrical tanks (diameter 9 m, height 7 m) up to the level of 2 to 3 m above the bottom.

The samples were taken away in 8 – 10 different positions in each tank through one circle outlet (diameter 600 mm) in the ceiling of the tank. Three samples (as a minimum) in different levels of the settled sludge were taken in each position using a remotely operated manipulator. The partial layers of the sludge and ion exchangers were different, usually they were very thick or hard, having been more than 15 years settled in the tanks.

The results of the alpha, beta, gamma radiochemical analyses, optical microscopy and laser spectral analyses of the chemical elements content in the taken samples served for the selection and proving of a suitable technology for the solidification of these radwaste.

2.5 Cleaning of the VVER-440 reactor vessel bottom

During the operation, different impurities in the form of solid particles or sludge are settled on the bottom of the reactor vessel. These impurities consists of loosened corrosion layer, metal sawdust, tiny pieces of activated metal, plastics, textiles, rest of lubricants, deposits and chemical precipitates. The presence of these impurities prevents the thorough defectoscopic inspection of the reactor vessel bottom during the reactor shut-down. Late method of cleaning using a sewage pump did not guaranteed a quantitative retrieval of these impurities from the vessel bottom and, moreover, these active impurities settled down on the lower parts of the pipes and collecting tanks during the pumping off having a negative impact on the radiation situation around the touched technological site.

The newly involved procedure for the cleaning of the reactor bottom is based on the principle of a suction pump and a subsequent trapping of the removed impurities in the shielded double-step filter. Suction system is installed on a remotely operated rotary manipulating platform which is positioned on the jointing plane of the reactor. This rotary platform serves for the systematic movement of the ejector suction nozzle along the complete surface of the reactor vessel bottom. The course of the cleaning procedure and the movement of the suction device is controlled from the control station and checked by a water-proof, radiation resistant camera. The principal schema of this equipment is showed in the Figure 4. This procedure has been used four times to clean the reactor vessel bottoms.

Representative samples of trapped impurities are taken away from the shielded filters and, subsequently, they are treated in the laboratory as follows:
- dose rate measurements in the contact with the sample container;
- the macrostructure documentation of single samples;
- selection of atypical objects;
- dose rate measurements of the selected objects;
- weighing of the selected objects;
- documentation of the selected objects;
3. CONCLUSIONS

Removal and collecting of the radioactive sludge and solid deposits from the different objects represents a significant problem. Monitoring, characterization, performing of the non-active tests and remotely operated manipulators should contribute to the solving oh this problem.

Figure 4. Principal schema of the procedure and equipment is showed in the picture for the cleaning of reactor vessel bottom