Decommissioning of the NPP A-1 Heavy Water Management System – 15121

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ABSTRACT

The paper deals with experience and techniques in the application of decontamination technology and remotely controlled robotic devices for the decontamination and dismantling of the heavy water management system during undergoing decommissioning process of the A-1 NPP as well as treatment of arising liquid waste All of these activities are characterized by high level of radioactivity and contamination.

During operation of the A-1 NPP the heavy water management system fulfilled several functions: (1) cooling of the moderator, (2) topping up of the moderator in the active zone, (3) drainage, feed and storage of heavy water, (4) capture of leaked heavy water. Closely associated with heavy water management were systems for separation and isotopic purification of heavy water (distilling station, removing organic impurities station, isotopic purification station).

The NPP heavy water system is located inside the power block building in several rooms where the inner surface contamination is up to the level of 10E4 Bq.cm-2, dose rate up to 15,0 mGy.h-1 and the feeding pipeline contained liquid RAW with high tritium content.

Pre-dismantling decontamination of the heavy water management system and associated systems had to be performed with the intention of improving the radiation situation, i.e. reducing contamination of internal surface and dose rates in the vicinity of the equipment.

Various sophisticated procedures such as retrieval of sludge using remotely operated devices and loop chemical decontamination of internal surfaces were applied. The generated radioactive waste such as spent decontamination solutions and sludge were immediately solidified on-site into a geopolymer matrix using a mobile conditioning facility.

For dismantling and fragmentation of some devices, mobile robotic systems MT80 and MT15 were applied which had been developed, designed and constructed as general-purpose decommissioning equipment. Special tooling was developed for application with the robots, such as hydraulic shears, circular saw, reciprocating saw, circular pipe cutter and a system for quick tool-change without direct intervention of the operators. Most of the operations are remotely controlled on basis of visual information from four cameras, with consistent radiation protection of the operators.

The implementation of partial decommissioning tasks in such hard and unfavorable radiation conditions (moreover accompanied by generation of specific high-content alpha radwaste) has introduced in practice several new unique decontamination and dismantling techniques and new procedures for the effective on-site processing of generated secondary radioactive waste, including sludge and sorbents. These advantageous techniques, equipment and experience will be exploited in the continuation of the A-1 NPP decommissioning process which has been organized according to distinctively licensed phases and are also being applied in the decommissioning of other NPP in Slovakia as well as abroad.

INTRODUCTION

Nuclear Power Plant JE A-1 is situated in the locality of Jaslovské Bohunice, Slovak Republic. In the present time, the following nuclear facilities are situated in the locality of Jaslovské Bohunice, (Figure 1):

- JE A1 (since 1980 in decommissioning)
- JE V1 (operated reactors VVER 230) gradually being shut down from operation since 2006, or 2008. A planned process of its continual decommissioning began in 2011
- JE V2 (operated reactors VVER 213)
- Interim-storage of spent fuel, wet type (MSVP)
- TSÚ RAW (bituminization, cementation, incineration, compacting, and other forms of RAW fixation)

Figure 1. The Bohunice nuclear site in Slovakia

A-1 NPP was built in the 50s of the last century as the pilot project for the development of the generation of CO_2 cooled, and heavy water moderated reactors with natural metallic uranium as the fuel, 150 MWe. It was operated in the period from 1972 to 1977. During the operation two events occurred, the second accident caused the damage of the spent fuel in the core (INES 4). After several efforts to remove the technical defects of the reactor and steam generators, finally in 1979 the Government decided on permanent shutdown of this nuclear power plant and its following liquidation. At the time, no decommissioning infrastructure, no experience on waste management and no legislation with respect to decommissioning of nuclear power plants were available.

Accidents Description and Consequences

The first accident (failure of the closing mechanism of technological channel) happened in January, 1976. Fresh fuel assembly (together with the non- locked technological plug) was ejected into the reactor hall. Carbon dioxide coolant escaped for a short time from the reactor channel under the sub-operational pressure (shutdown of reactor) until the refueling machine was reconnected to the opened technological channel and stopped coolant escape. Consequent drop of coolant pressure caused problems with cooling down of the core of reactor. Some fuel assemblies were overheated resulting in damage of fuel and release of fission products into the primary circuit. After sealing of primary circuit by refueling/loading machine, the reactor was cooled down.

NPP A-1 recommenced the operation after channels plug reconstruction and inspection in September 1976 and operation continued until the second accident.
During refueling in February 1977, a non-conforming fuel assembly (internal cross section was partly blocked by silica gel - used for drying of fresh fuel during transport and storage) was charged into the reactor core. Reduced coolant flow stream caused local overheating of fuel and consequent damage/melting of technological channel (heavy water tank tube). As a result the loss of barriers integrity between fuel, carbon dioxide coolant and heavy water moderator took place. Extensive corrosion damage of fuel cladding by heavy water saturated with carbon dioxide occurred. The integrity of steam generator tubes was also influenced.

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 the second accident, the heavy water circuit was also contaminated – the evaporator surface of moderator distilling station 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.

NPP Decommissioning

Considering this non-standard shutdown situation, decommissioning has been organized according to distinctively licensed phases, which allows collecting input data for the next stage during the running decommissioning stage. The aim of such selected concept of A-1 power plant decommissioning is, on the one hand, its liquidation and, at the same time, building an infrastructure (TSÚ RAW - Technologies for RAW treatment and conditioning) on its territory and in its object system, necessary for A-1 decommissioning activities, as well as for future decommissioning of V-1, V-2 nuclear power plants, and eventually, also for Mochovce power plant. Thus, the A-1 objects which are utilizable for TSÚ RAW operation are gradually, after the removal of original A-1 equipment inventory or after their reconstruction, re-reclassified into TSÚ RAW nuclear installation.

The overall A1 NPP decommissioning has the following scheme:

- Transition period 1977-1999 under operational license, at the end with no spent fuel in A1 NPP.
- First licensed decommissioning phase 1999-2008, resulting in a radiantly safe state, which means removal of all the accident consequences, which could negatively influence the environment.
- Final decommissioning 2009-2033 in four individually licensed decommissioning phases (Stages II-V), starting from low-contaminated and simple systems up to the most contaminated systems and the reactor.

Since 2009 Stage II of A-1 NPP decommissioning has been in process (2009-2016). Its target is the decommissioning of external objects as well as of production unit equipment (e.g. heavy water management system).

HEAVY WATER MANAGEMENT SYSTEM

The heavy water management system as one of the A1 NPP nuclear auxiliary systems is located inside the power block building in several rooms. Installations met the following functions in the technological process:

- Cooling of the moderator
- Compensation of the moderator in the active zone

- Drainage, feeding and storage of heavy water
- Capture and collection of the leakages of heavy water

Systems for separation and isotopic cleaning of heavy water (distilling station, organic impurities purification station, isotopic purification station) were closely connected with the heavy water management system.

Contamination

The construction material of heavy water circuit and auxiliary systems that were in contact with heavy water is austenitic stainless steel (18 % Cr, 8 % Ni). The internal surfaces of heavy water circuit were contaminated in two manners:

a) During normal operation of the power plant radionuclides were gradually deposited on internal surface of heavy water systems in the form of products of corrosion and of chemical reactions. In the main part these radionuclides were formed by active corrosion products that were released into the primary circuit during the corrosion of gas piping that was made from low alloy steel. The corrosion of heavy water equipment itself was very low due to the use of high quality steel and low operating temperature. The contamination in heavy water systems therefore consists of, by and large, deposits and sediments that do not hold fast to the base material.

During the power plant operation internal surface of equipment was corroding gradually (particularly the reactor vessel where the rate of corrosion relative to aluminium was reaching 0.15 kg per day at the beginning of the plant operation). Corrosion products were activated by neutrons when in the active zone. They were then distributed throughout the heavy water circuit and deposited and accumulated on the internal surface, depending on particular conditions (temperature, pressure, rate of flow, complexity and shape of equipment). Fission products and transurans contributed to the contamination to a lesser extent; they were a consequence of the coolant (carbon dioxide) coming into contact with and dissolving in the heavy water. Another result of neutron activation was the emergence of tritium (tritium water) that represented a significant risk during water evaporation and production of active water vapor.

b) During the first accident there was a step increase in the volume activity of radionuclides in heavy water. In this case contamination was mainly formed by fission products and transurans. During the second accident a substantial volume of heavy water penetrated the primary circuit for a short time and came into direct contact with the damaged fuel elements. After the accident heavy water was pumped back into the heavy water circuit and contaminated heavy water management systems and the distilling station further.

After the reactor shutdown in 1977 the dominant radionuclide in the heavy water circuit was 60Co. Because of differences in half-lives the ratio of 60Co to 137Cs gradually became equal so that nowadays they are the two dominant gamma nuclides in all monitored heavy water equipment. The activity of beta sources, represented mainly by 90Sr, is about the same as gamma sources. The activity of alpha sources is lower by one to two orders of magnitude.

Three identical cooling loops were used to cool the moderator. As the construction and spatial arrangements are identical and the same radioactive medium is used to circulate through them under equal conditions (pressure, temperature, rate of flow), the radioactive state is very similar. Two dominant gamma radionuclides (137Cs a 60Co) are found in approximately equal measure in the contamination on internal surface of heavy water piping: whilst in hot branches 137Cs slightly prevails, in cold branches it is 60Co. Contamination of hot branches is higher than cold branches by an order of magnitude. Heavy water had been drained from the cooling loops and collectors; we have not found any presence of it in these systems during monitoring.

Having drained the heavy water from the cooling circuit (including that which had penetrated the primary circuit) after the accident and reactor shutdown, all the water was subsequently distilled in the evaporator

and then purified from light water in the isotopic purification station and stored in the high pressure tanks. When being drained from the primary circuit it brought contamination and impurities from the primary circuit into these systems (as can be witnessed in the content of beryllium and magnesium in the sludge that had settled on the bottom of the heavy water release tank). This explains why the evaporator (loop 1) is the most contaminated piece of equipment of the heavy water distilling station.
We have found various amounts of free deposits, sludge and liquid phase in all the heavy water systems except for isotopic purification station. When decontaminating these systems the first step will have to be to drain the liquids and remove and process the sludge. Only after this will one be able to begin to decontaminate internal surface of equipment.

Decommissioning of Heavy Water Management Sub-Systems - General Approach
Typically, the decommissioning of the Heavy Water Management Sub- System passes through three basic steps:

- Pre-dismantling decontamination (if necessary);
- Dismantling and segmentation;
- Post-dismantling decontamination.

In most cases, pre-dismantling decontamination was the first activity carried out. The objective of pre-dismantling decontamination of the heavy water management system and associated systems is to improve the radiation situation, i.e. to reduce contamination of internal surface and dose rates in the vicinity of equipment. Follow-up operations can then be undertaken, such as the removal of objects from rooms, dismantling of equipment etc. Especially in case of operations taking a long time (e.g. fragmentation of metallic materials), remote controlled manipulators are used.
Radiation situation in some rooms is acceptable and one could therefore consider dismantling equipment that is there without first decontaminating the internal surface. However, given the comparatively high presence of alpha and beta radionuclides in surface contamination and hence also in the radioactive aerosols that will be one of the results of dismantling, it may be advisable to perform pre-dismantling decontamination of this equipment as well. Chemical decontamination was selected as the basic method for pre-dismantling decontamination of internal surface of heavy water systems at A1 NPP.

The decommissioned installations can be divided into following:

- Heavy water storage and capture system
- Heavy water purification system
- Heavy water cooling circuit

The decommissioning of the above mentioned sub-systems is described in more or less detail below.

HEAVY WATER STORAGE AND CAPTURE SYSTEM DECOMMISSIONING

The heavy water storage and capture system could store the entire volume of heavy water from the active zone if it was necessary because of maintenance or an accident. The storage system comprises of:

- High pressure tanks (4)
- Low pressure tank
- Heavy water drainage tanks (2)
- Heavy water leakage tank
- Interconnecting pipework

So far, the decommissioning of two heavy water drainage tanks and one collecting tank for D_2O+H_2O leakages has been implemented. The pre-dismantling decontamination procedures were very similar in all cases.
First, it was necessary to remove radioactive sludge and loose sediments from the bottom and walls of all tanks. A circular opening had to be made in the front wall of each tank. The sludge was pumped out by a sludge ejection pump with a remotely operated vehicle that was used to move a suction hose operating on the waste surface. The removed sludge was collected in drums and subsequently solidified in special mobile equipment to the form suitable for safe manipulation and transport. Packages (drums) with solidified waste were then transferred to the conditioning unit.

In order to minimize occurrence of secondary waste, decontamination of the internal surface of the tank was performed in two ways. The lower, most contaminated part of the tank was flooded by a chemical decontamination solution. The remaining surface was sprayed by this solution using a specially adapted injector frame with a rotating set of jets. With the help of a submersible pump the solution was driven onto the injector frame and sprayed uniformly by the rotating jets onto the internal walls of the tank, along which it ran down to the bottom together with the dissolved deposits.
As a result of this procedure the radiation situation was radically improved and follow-up operations could then be undertaken (on-site non-thermal segmentation of tanks). The rooms were completely cleaned and prepared for the relevant uses in the decommissioning framework.

The High and Low pressure tanks will be dealt with later, during the next NPP decommissioning stage.

HEAVY WATER PURIFICATION SYSTEMS DECOMMISSIONING

General Description

Part of the heavy water purification system is the distilling station and the purpose of the distilling station was the following:

- Continuous purification of heavy water in the cooling circuit from products of corrosion of the reactor vessel. The objective was to keep the concentration of the corrosion products under 10 $mg.dm^{-3}$.
- Periodic processing of CO_2 pulp arriving from the evaporator in the CO_2 cleaning circuit. Heavy water was captured from the pulp during this process.
- Periodic purification of heavy water that had leaked from the heavy water circuit on the floor in the rooms and was captured through the special stainless steel draining system in the collecting tank for D2O+H2O leakages.
- Re-distilling of the whole volume of heavy water (during an accident or reactor outage) after it has been pumped into high pressure tanks.

The distilling station consists of two identical mirror-oriented evaporator loops (see figure 2). Each loop consists of the evaporator and its electric furnace, the heavy water separator, the heavy water condenser and interconnecting pipe work. Common equipment for both loops comprises a heavy water degasser, washing pump, oil filter, vacuum pump and interconnecting pipework. Individual pieces of equipment are situated inside the separate rooms of the main production unit building

The heavy water isotopic purification station was used to process diluted water and remove fresh water (H2O) from the moderator (heavy water).
During operation the moderator used to get adulterated by a certain amount of fresh water. This reduced the

reactivity margin and it was therefore necessary to purify the moderator.
Organic impurity purification station was used to burn organic species in gaseous phase on a catalytic converter.

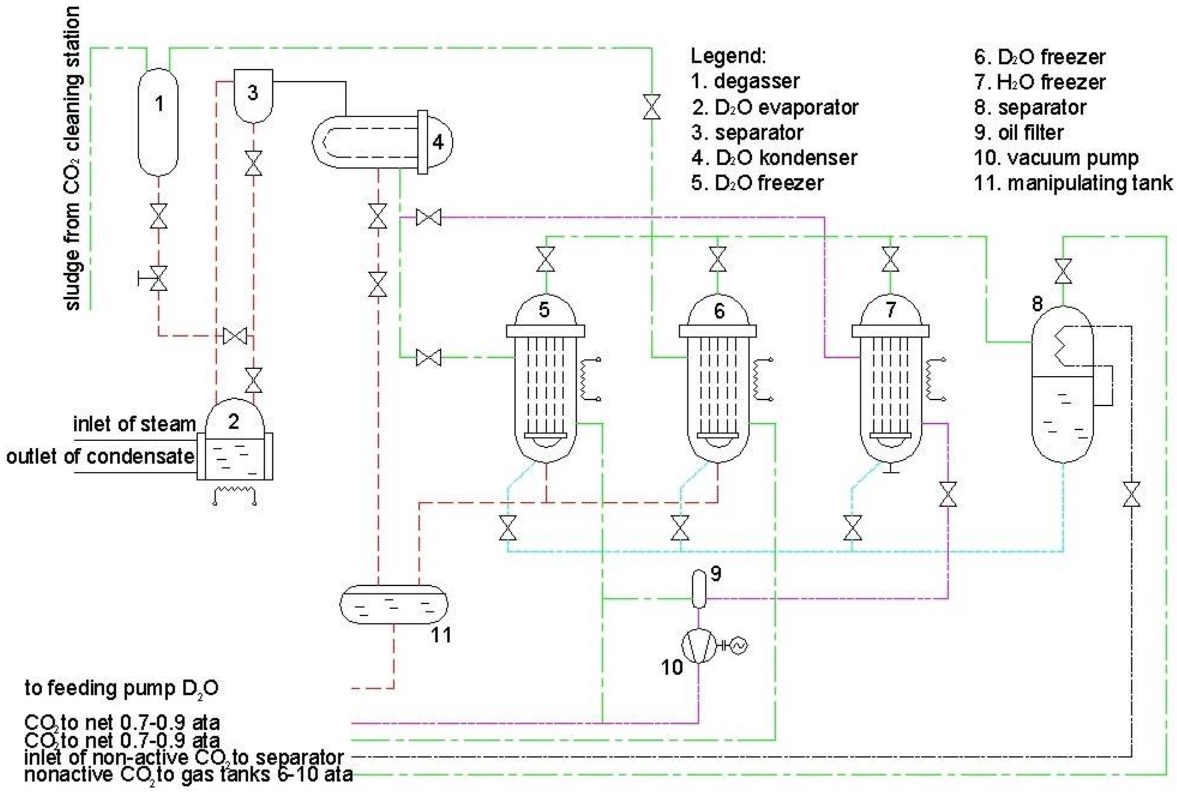

Figure 2. Schema of D_2O distilling station and freezers

During the preceding stage, decommissioning of the distilling station parts, the isotopic purification station and the organic impurity purification station had been carried out.

Evaporators Decommissioning

Decommissioning of evaporators was implemented in previous period 20111 - 2013.
Evaporators were most contaminated parts of distilling station, mainly the evaporator of distilling loop No. 1 that was used for the re-distilling of the whole volume of heavy water during a reactor outage or after accident. Evaporators were located inside Rooms 220 and 219 inside the power block building.
Presence of liquid and sludge was established in the evaporators during initial monitoring.
Samples of liquid radioactive waste with sludge components were taken from the evaporator core. Sample analysis proved necessity of pre-dismantling decontamination:

- total gamma activity 6.23×10^7 Bq.dm^{-3} liquid phase, ^{241}Am alpha activity 1.33×10^3 Bq.dm^{-3}, tritium activity 9.37×10^9 Bq.dm^{-3}
- total gamma activity 4.09×10^7 Bq.dm^{-3} sludge phase, ^{241}Am alpha activity 9.19×10^4 Bq.dm^{-3}.

The basic pre-decontamination procedure is characterized by:

- Pumping out the liquid phase with high content of tritium,
- Removal of sludge from the evaporator bottom,

- Chemical decontamination of internal surfaces.

The liquid phase and radioactive sludge were collected in 60 dm^3 drums and directly in these drums the waste was solidified into geopolymer matrix using mobile facility.
The decontamination of internal surface of the evaporator was performed in two ways. The lower, most contaminated part of the evaporator was flooded by a chemical decontamination solution. The remaining surface was sprayed by this solution using a specially adapted injector frame with a rotating set of jets. With help of a submersible pump the solution was driven onto the injector frame and sprayed uniformly by the rotating jets on internal walls of the evaporator, along which it run down to the bottom together with dissolved deposits.
Having decontaminated the internal parts of evaporators, the gradual complete dismantling of them followed.

Manipulator MT80 was used for the dismantling procedure. It is a remote controlled handling device with hydraulic drives enabling handling of loads of up to 80 kg of total weight and consisting of the following five function units:

- manipulating arm
- control panel
- regulation module
- hydraulic power unit
- interconnecting cables and pressure hoses

Basic dimensions and weight:

- length 1 938 mm, height 537 mm, width 320 mm, weight 150 kg

Kinematic parameters:

- maximum reach of manipulator: 1 800 mm
- No. of degrees of freedom: 6
- maximum circumferential velocity for manipulation: 0,2 m/s
- angles of rotation:
  - base -130° to +130°
  - arm 0° to +125°
  - forearm -135° to +85°
  - wrist angle -88° to +88°
  - wrist deflection - 88° to +88°
- jaws rotation - 102° to +102°
- jaws opening - 0 - 104 (102 - 206)mm

The tooling head is located on the terminal element of the manipulator MT80 arm. It consists of a felloe and a guiding section. It is fixed in place by means of a gripping joint and is secured against axial movement by a bolt. The front part of the head is provided with two centring pins the purpose of which is to secure reliable centring function during sliding-in of the guiding system holding the tool (circular saw, hydraulic shears, reciprocating saw, etc.).

The parts that had to undergo fragmentation first were those that presented an obstacle and limited the maneuvering possibilities of the manipulator in the area. These were the connecting rods for distant control of the armatures, insulated piping situated between the front wall (with the technological opening) and the evaporator by cutting it with a reciprocating saw into lengths of approx. 400 mm. Some of pipes were cut by hydraulic shears. Dismantling and fragmentation of the evaporator started from the front (accessible) section in the following order:

- Insulation sheathing – front section
- Cover and jacket – front section
- Wash water and pulp piping –interior section
- Cover and jacket – rear section
- Insulation sheathing – rear section
- Pedestal – location of the heating element
- Heating element

After fragmentation works were finished and all the fragments, the MT80 and the mobile truck were removed from the room, the decontamination work was carried out. Rooms 200 and 219 remained empty, decontaminated and prepared for further use.

Figure 3. Room 200 after dismantling

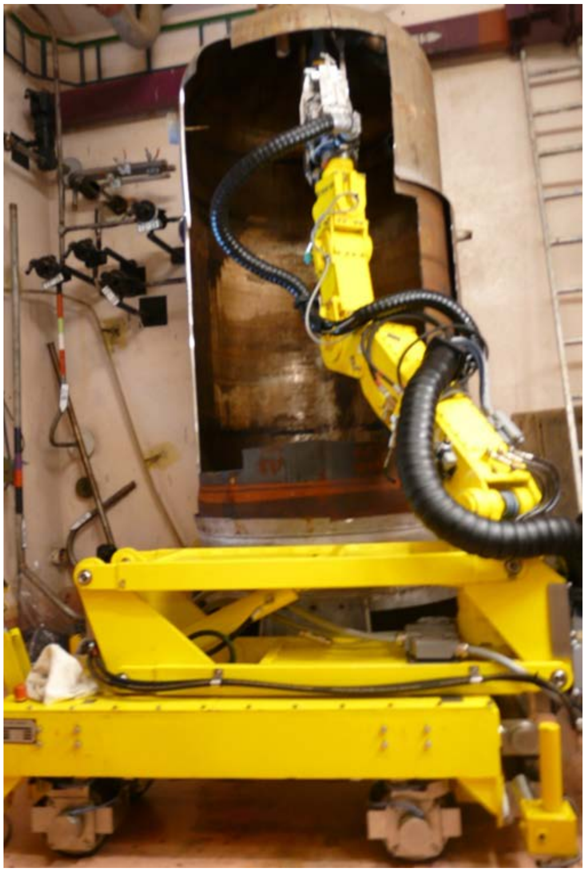

Figure 4. Manipulator MT 80 in operation

Decommissioning of the Isotopic Purification Station

The isotopic Purification Station had already been decommissioned. Surface activity on external and internal surfaces of isotopic purification station equipment was low. Therefore the pre-dismantling decontamination involved only the wiping external surface with moisture rags and subsequently rinsing internal surface with water before the dismantling and disposal of equipment.

Individual systems of the station were then gradually dismantled and segmented using non-thermal techniques. Segments were transported to the decontamination center and decontaminated in electrochemical and ultrasonic baths up to levels enabling the release of the scrap to the environment for unconditioned re-use. The rooms where the station was installed are cleaned, decontaminated.

In similar way the other parts of heavy water purification systems were already decommissioned (Organic Impurities Purification station, Heavy Water separator, condenser and degasser).

HEAVY WATER COOLING CIRCUIT DECOMMISSIONING

Basic Description

Heavy water served as the moderator of neutrons in the active zone. It heated up during the slowing down of neutrons, absorption of radiation and transfer of heat from the fuel channels. To prevent boiling and at the same time keep evaporation to an absolute minimum heavy water was cooled. Three independent cooling loops for heavy water were used for this purpose. Each of them consisted of:

- Circulation pump
- Double bodied cooler
- Connecting piping with valves

From the reactor vessel heavy water passed into a common hot collector and from there was pumped by the circulation pumps into individual loops. It then flowed via a double bodied cooler into the cold collector and from there back into the avial vessel.
Cold and hot heavy water collectors were installed in Room 104 (-14.00 m) below the bottom of the avial vessel (see Figure 5). Hot and cold branches of all three circulation loops were connected to the appropriate collector in this room. The piping proceeds further to a higher level (-10.00 m) and passes through Rooms 216 (loop 1), 217 (loop 2) and 218 (loop 3) where main remote controlled closing valves are installed on all hot and cold branches. The pipes lead further to the next floor (-6.0 m) into Rooms 314, 315 and 316. Circulation pumps are installed on the hot branches there whilst return valves can be found on cold branches.

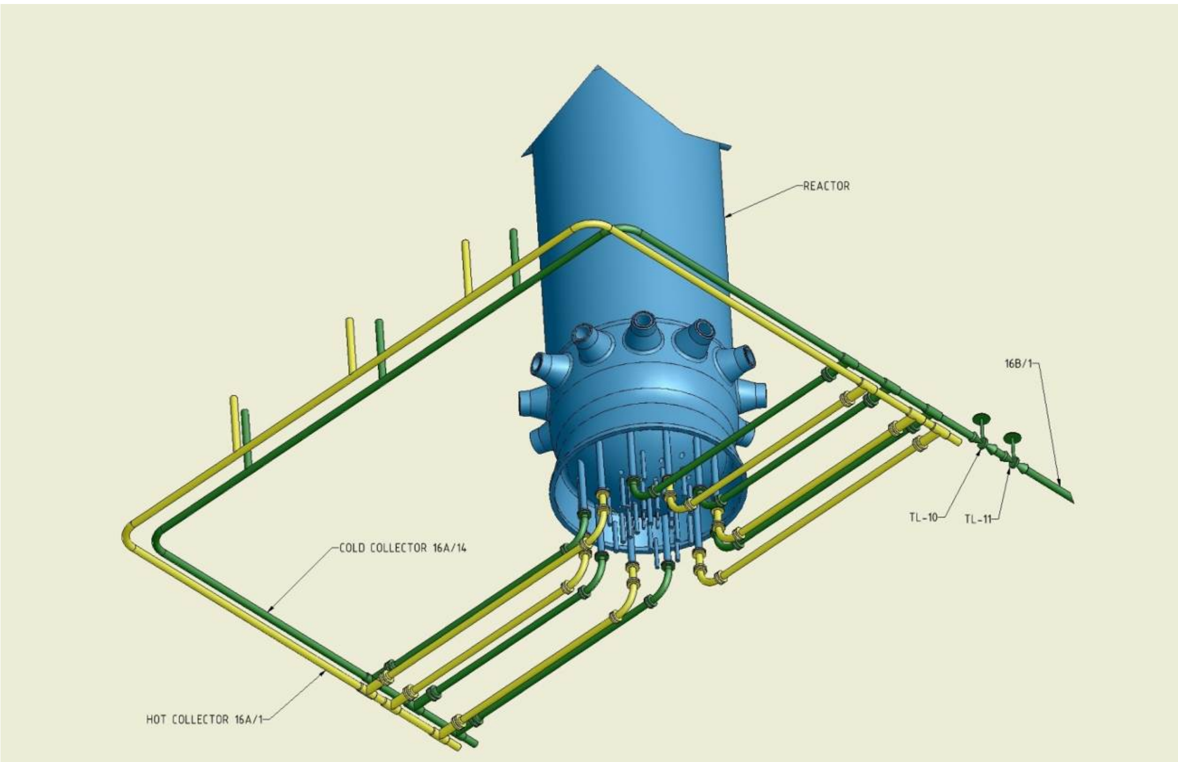

Figure 5. 3D model of heavy water collectors

Heavy water collector: a pipe with diameter ø 219 x 10 mm. Internal volume of one collector is 1.40 m3, internal surface area of one collector is 27.0 m2. It is constructed from stainless steel 17 246.1.
Closing valves: Two valves are installed in each cooling loop – one at the circulation pump input and the other at the output from the heavy water cooler – six valves altogether. Internal diameter of the valves is 200 mm, design operational pressure 10 MPa. They are made from austenitic Cr-Ni steel, the mass of one valve is 1350 kg. They are electrically driven.
Additionally, non-return valves are installed at the output from the coolers – three valves altogether. Internal diameter of these valves is 200 mm, design operational pressure 10 MPa. They are made from austenitic Cr-Ni steel.

Heavy water circulation pump: This was a centrifugal, without seals, vertical, one-stage pump with single sided input, 2810 mm high, with a 1650 x 1350 mm footprint and mass 5450 kg. The motor was cooled by heavy water which was then cooled in an auxiliary circuit.
The pump consists of hydraulic part, electric motor (stator, rotor) and bearings. It is installed in a stand that is anchored into a concrete slab on the floor. Inlet and outlet fittings are welded to the circulation piping. The motor with its flywheel and bearing is removable. Different materials had been used in its manufacture; those that would come into contact with heavy water were made from stainless steel.
Heavy water cooler (6): a vertical cylindrical vessel of height 5713 mm, diameter 1200 mm, volume of internal pipes 0.75 m3, volume of space between internal pipes 2.4 m3, heat transfer area 432 m2, thickness of outer walls 8 mm, mass 8950 kg. Inside the cooler there are 865 U shaped pipes (ø 12 x 1.25 mm), whose ends are coupled to the input and output collectors. Those parts that were in contact with heavy water had been made from austenitic stainless steel, the other parts from carbon steel.
Internal volume of one loop (without the cooler) is about 1.1 m3, internal surface area 21.0 m2

Pre-Dismantling Decontamination

The parts of the cooling circuit that are to be decontaminated are heavy water collectors and three cooling loops. The cooling circuit has a large internal volume and it is spread out over a large area. Also, all the heavy water coolers have already been dismantled. For these reasons the cooling circuit are not decontaminated in one lot but are divided into a number of segments:

- Decontamination of hot and cold collectors
- Decontamination of individual cooling loops (each of them separately)
- Individual heavy water coolers

The part to be decontaminated will be separated from the rest by closing the appropriate valves on interconnecting pipework, dismantling of the interconnecting pipework and plugging up or reconnecting the resulting openings etc. Decontaminated equipment will then be made into a closed circuit with the help of the external decontamination system that provides the basic facilities for closed circuit decontamination – feeding, circulation and drainage of decontamination and rinsing solutions as well as some other specific functions.

Pre-Dismantling Decontamination of Heavy Water Collectors

The pre-dismantling decontamination of heavy water collectors was implemented in 2014.
Decontamination included the following steps:

- Preparatory work.
- Establishment of the work station. Decontamination and auxiliary equipment was gradually delivered and sited. This included a mobile system for closed circuit chemical decontamination with accessories, equipment and materials for the preparation and processing of chemical decontamination solutions and monitoring and control equipment
- Closure of collector circuit. The hot collector was separated from the in-reactor avial vessel by cutting six output pipes (Φ 133x8 mm). Similarly, cold collector was separated by cutting six input pipes to the avial vessel (Φ 133x8 mm). A cut out of the length of about 1 m was removed from each of the twelve pipes. The pipes were closed by welded plugs. Fittings were welded to appropriate places for fixing the output and input hoses of the closed circuit decontamination system. The input and output hoses of the closed circuit decontamination system were connected to the prepared fittings
- Feeding of decontamination solution into collector. The decontamination solution was added via the closed circuit decontamination system into collectors. Inorganic acid with additives (total concentration 5.0 $\%_{vol.}$) was used for the decontamination.

- Circulation of the solution in heavy water collectors.
- Drainage of the solution from the heavy water collectors. After the completion of the decontamination cycle the chemical solution was drained from the collectors and treated.
- Rinsing of collectors. Internal surfaces of the collectors were rinsed by water. This principal activity consisted of feeding, circulation and drainage of water from the collectors. Closed circuit decontamination system was used to feed, circulate and drain the rinsing water. Rinsing water was treated together with spent decontamination solution.

The decontamination cycle (feeding, circulation, draining, rinsing) was repeated twice. The residual surface contamination dropped from initial values of 3.0E3 Bq.cm-2 up to 5.0 Bq.cm-2.

Pre-Dismantling Decontamination of Heavy Colling Loops

The pre-dismantling decontamination of heavy cooling loops (except coolers) will be launched in 2015. Three separated cooling loops are the subject of the work. The loops will be decontaminated by closed circuit chemical decontamination method. From the time sequence point of view, decontamination of each heavy water cooling loop can be divided into the following tasks and principal activities:

- Preparatory work.
- Establishment of the work station. Mobile system for closed circuit chemical decontamination with accessories will be installed in the decontaminated equipment.
- Closure of collector circuit. The key operation will be the interconnection of hot and cold branches of the cooling loop. These branches were originally connected via a double bodied cooler that was installed in a separate room. During the dismantling of the coolers, input and output pipes were cut and plugged level with the floor in that room and the room is now inaccessible. Hot and cold branches will therefore be connected in the upper part of room below. Fittings will be welded to the ends of cold and hot branches in lower part for fixing the output and input hoses of the closed circuit decontamination system. The input and output hoses of the closed circuit decontamination system will be connected to the prepared fittings
- Feeding of decontamination solution into collector. Inorganic acid with additives (total concentration 3.0 $\%_{vol.}$) will be used for the decontamination.
- Circulation of the solution in heavy water collectors.
- Drainage of the solution from the heavy water cooling loop.
- Rinsing of collectors.

The decontamination cycle will be repeated twice to reach limits for application of non-thermal dismantlement and segmentation technologies.

Pre-Dismantling Decontamination of Heavy Water Coolers

The start of Heavy Water coolers decontamination has not been firmly specified yet. Two methods are under consideration:

1. Pre-dismantling chemical decontamination of cooling pipes followed by segmentation,
2. Segmentation of cooler, separation of non-contaminated parts and re-melting of contaminated cooling pipes.

Dismantlement of Heavy Water Collectors

Dismantling activities are being carried out with help of Fragmenting Mobile Teleoperator MT15. It is a remote-controlled teleoperator with a four-track undercarriage and a modular system of the following exchangeable technological superstructures:

- Handling arm
- Fragmenting system
- Decontamination system

Basic technical specification of MT 15 teleoperator:

- manipulating arm payload 15kg
- fragmentation arm payload 25kg
- weight of platform   119 kg
- installed power 800 W

The teleoperator is driven by an electric drive powered from batteries located within the undercarriage, with alternative possibility of power supply via cable. The outdoor version can be provided with an undercarriage with combustion engine and power generator. The control PC ensures the proper cooperation of all teleoperator modules. A pulse converter unit controls the drive of six motors of the undercarriage or seven motors of the handling arm. Communication modems ensure the transmission of control commands and data feedback on the condition of the teleoperator. The teleoperator camera system consists of six cameras. For purpose of perfect image perception the operator may wear a 3D helmet enabling stereoscopic display of the scene being picked up by the cameras.

In our case of piping systems liquidation the Fragmentation System used consists of a telescopic arm, fixing head and jigsaw effector. The telescopic arm is driven by a linear electric actuator and can reach the height of 4.5 m. The fixing head catches the pipe and stabilizes the saw for performing its operation.
The jigsaw effector saws the pipe into fragments of specified length.

The workplace also includes a remote controlled truck with lifting platform that is capable of gripping the fragment of piping after it has been cut off. The truck then carries the fragment out of the active zone. Platform carrying capacity is 75 kg and platform lift height is 570 - 2400 mm.

Figure 6. Manipulator MT15 in operation

The liquidation of piping in Room 104 proceeds as follows (see Figure 6):

- Cutting off of pipe fragment ø 219 x 10 mm approximately 1 200 mm long. The teleoperator is positioned below the piping to be cut and the teleoperator´s fragmenting head is brought close to the pipe. The gripper jaws catch the pipe. Cutting is executed by a jigsaw tool, which is pushed against the pipe. The free ends of the piping being cut are supported by mechanical supports.
- Pipe fragment handling and transport outside the Room 104. During the cutting of piping the pipe fragment is positioned in the trough of the remote controlled truck with lift platform. After the fragment has been cut off, the platform is lowered into bottom position. The truck transports the fragment into the hall outside the room.
- Placing of pipe fragment into prepared transport container
  The pipe fragment is grasped by the gripper of the pulley system that is attached to guides in the ceiling. It is hoisted into top position and carried above the transport container into which it is then placed. The gripper jaws open and the pulley is returned into initial position over the truck.

All operations during cutting, transport and placing of the fragment are remotely controlled from Room 108 and monitored on control panel displays. The operator is protected from the effects of radioactive radiation. The cameras located on the teleoperator enable the operator to correctly position the teleoperator in the workplace. Room 104 is also equipped by cameras with lighting mounted on the walls which enable correct positioning and movement of the truck.
Fragmentation works started in November 2014 and will be completed during 2015.

CONCLUSIONS

The progress of A-1 NPP decommissioning is influenced by the specific situation in A-1 NPP (accident, specific design features). It was not easy to apply the available decommissioning and waste management procedure techniques directly. In most cases, the techniques either had to be adapted to local conditions, or it was necessary to develop tailored procedures and relevant equipment in order to meet the conditions in A1 NPP.
On the other hand, due to the particularly demanding conditions in the field and the strongly contaminated A-1 NPP, a team of experts with special know-how in the field of decommissioning has grown up, and unique technological equipment enabling effective and safe work in environments with a high radiation level has been developed.
The remote controlled device was applied in such extent for the first time during decommissioning of the equipment located inside the main production unit building. The results achieved predetermine the manipulators MT80 and MT15 for further utilization during A-1 NPP decommissioning.