

Overview of Remote Handling Equipment Used for the NPP A1 Decommissioning - 12141

K. Kravarik*, J. Medved*, V. Michal**, A. Pekar*, M. Stubna*, L. Vargovcik***

*VUJE, Inc., Okružna 5, 918 64 Trnava, Slovakia

**IAEA, Wagramer Strasse 5, P.O.Box 100, A-1400 Vienna, Austria

***ZTS VVU Kosice, Inc., Juzna Trieda 95, 041 24 Kosice, Slovakia

ABSTRACT

The first Czechoslovak NPP A1 was in operation from 1972 to 1977 and it was finally shutdown due to an accident (level 4 according to the INES). The presence of radioactive, toxic or hazardous materials limits personnel access to facilities and therefore it is necessary to use remote handling technologies for some most difficult characterization, retrieval, decontamination and dismantling tasks.

The history of remote handling technologies utilization started in nineties when the spent nuclear fuel, including those fuel assemblies damaged during the accident, was prepared for the transport to Russia. Subsequent significant development of remote handling equipment continued during implementation of the NPP A1 decommissioning project - Stage I and ongoing Stage II. Company VUJE, Inc. is the general contractor for both mentioned stages of the decommissioning project.

Various remote handling manipulators and robotics arms were developed and used. It includes remotely controlled vehicle manipulator MT-15 used for characterisation tasks in hostile and radioactive environment, special robust manipulator DENAR-41 used for the decontamination of underground storage tanks and multi-purposes robotics arms MT-80 and MT-80A developed for variety of decontamination and dismantling tasks.

The heavy water evaporator facility dismantling is the current task performed remotely by robotics arm MT-80. The heavy water evaporator is located inside the main production building in the room No. 220 where loose surface contamination varies from 10 Bq/cm² to 1x10³ Bq/cm², dose rate is up to 1.5 mGy/h and the feeding pipeline contained liquid RAW with high tritium content.

INTRODUCTION

The A1 Nuclear Power Plant (NPP) in Jaslovské Bohunice, Slovak Republic, was the first Czechoslovak nuclear power plant. Its nominal electric output was 150 MW. Natural metal uranium was used as a fuel, heavy water as a moderator and carbon dioxide as a coolant. A1 NPP was in operation from 1972 to 1977 and was finally shutdown after an accident (level 4 according to the International Nuclear Event Scale). The government decided about the final shutdown of A1 NPP in 1979 on the bases of technical, economic and safety analyses. At that time, no legislation was available with respect to decommissioning of nuclear power plants. A1 NPP decommissioning concept and time schedule were approved by Slovak Government in 1992. The overall A1 NPP decommissioning time schedule is following:

- Transition period (1977-1999) under operational license, at the end of the period all spent fuel from A1 NPP was removed.
- First licensed decommissioning stage (1999-2008) resulting in a radiation safe state, which means removal of all the accident consequences that could negatively influence the environment.
- Final decommissioning (2009-2033) divided into four individually licensed decommissioning stages (Stages II-V), consecutive decommissioning from low contaminated and simple systems to the most contaminated systems and the reactor itself.

VUJE, Inc. (formerly Nuclear Power Plant Research Institute) has been chosen as a general supplier of the A1 NPP Decommissioning Project. During the transition period all spent fuel from the A1 NPP was transported to Russia. Some auxiliary buildings have already been decommissioned to the green field. The part of turbine building is used for processing and storage of radioactive waste.

Since 2009 Stage II of A1 NPP decommissioning has been performed (to 2016). Its target is decommissioning of external objects as well as of production unit's equipment (e.g. heavy water evaporator facility). At the end of this stage only two A1 objects (Reactor building and Electrical building) will be left for the next decommissioning stages.

The presence of radioactive, toxic and hazardous materials limits personal access to some facilities. Therefore it is necessary and also very useful, in many specific cases, to use advanced computer-aided and remote technologies, especially for decontamination and dismantling. These technologies significantly contribute to safer and low-cost decommissioning.

In the following paragraphs, manipulators developed and used at VUJE, Inc. will be described together with fields of their application. Example of the heavy water evaporator facility dismantling, currently performed remotely by robotics arm MT-80A, is described in detail.

MANIPULATORS USED IN A1 NPP DECOMMISSIONING PROJECT

MT-15 Universal Mobile Manipulator

MT-15 is a mobile remotely control manipulator, which has been developed for inspection tasks in the radioactive environment. It is modular system, which can be equipped with analyse or decontamination unit.

The manipulator MT-15 consists of remote vehicle, which carries the manipulator arm and the working unit. The vehicle has four separate tracks, which can be tilted. With the tracks raised up or down the manipulator can make 180° turns within the circle with diameter \varnothing 1100 mm. The tilting tracks enable the manipulator to crawl over 200 mm high obstacles. The vehicle is electrically powered from the accumulator (24 V), which is carried on vehicle, or from an extern resource (length of cable 40 m).

Manipulator arm is electrically powered and it has 4 degrees of freedom. Its reach is 1500 mm and payload is 15 kg. The wrist of the manipulator can be equipped with wide variety of tools and can be rotated n x 360°. Two cameras and light assemblies provide

visual feedback for remote operation. Manipulator is waterproof and can be easily decontaminated. The main parameters of MT-15 are as follows:

- with of vehicle: 570 mm
- length of vehicle: 1340 mm
- height of vehicle: 518 mm
- tilting of manipulator's tracks: $\pm 55^\circ$
- shoulder yaw: $\pm 45^\circ$
- shoulder pitch: -30° up to $+105^\circ$
- elbow pitch: $+105^\circ$
- wrist yaw: $\pm 90^\circ$
- reach: 1500 mm
- payload: 15 kg

The manipulator MT-15 is designed for recognition and analysing tasks. Mock up tests of M-15 were successfully done in 2000. Since then, it has been used for picking up of radioactive samples, measurement of contamination level and rate of radiation. However, it can be also used for light duty task like cutting, drilling, vacuum cleaning of floors and removing radioactive waste.

MT-80 General Purpose Manipulator

Nuclear decontamination and decommissioning tasks include disassembly of technological equipment, cutting pipes, retrieval of radioactive waste materials, and decontamination of floors and walls. The general-purpose manipulator MT-80 has been developed for those heavy duty tasks.

The manipulator MT-80 (Fig. 1) is a robust, powerful, hydraulically powered, high dexterity manipulator designed to perform various remote tasks in nuclear installation. The hydraulic arm uses 6 degrees of freedom. It is made of special titanium-aluminium alloy. Manipulator has an 1800 mm reach and its payload is 80 kg at full extension. The wrist of the manipulator can be equipped with necessary dismantling or decontamination tools. The hydraulic actuators are used for actuating and each of these actuators has a build-in position sensor. The main hydraulic aggregate is placed in separate steel box. The main parameters of MT-80 are as follows:

- shoulder yaw: $\pm 130^\circ$
- shoulder pitch: $+136^\circ$
- elbow pitch from: -136° to $+100^\circ$
- wrist pitch: $\pm 90^\circ$
- wrist yaw: $\pm 90^\circ$
- wrist roll: $\pm 135^\circ$
- reach: 1800 mm
- payload: 80 kg
- weight: 140 kg

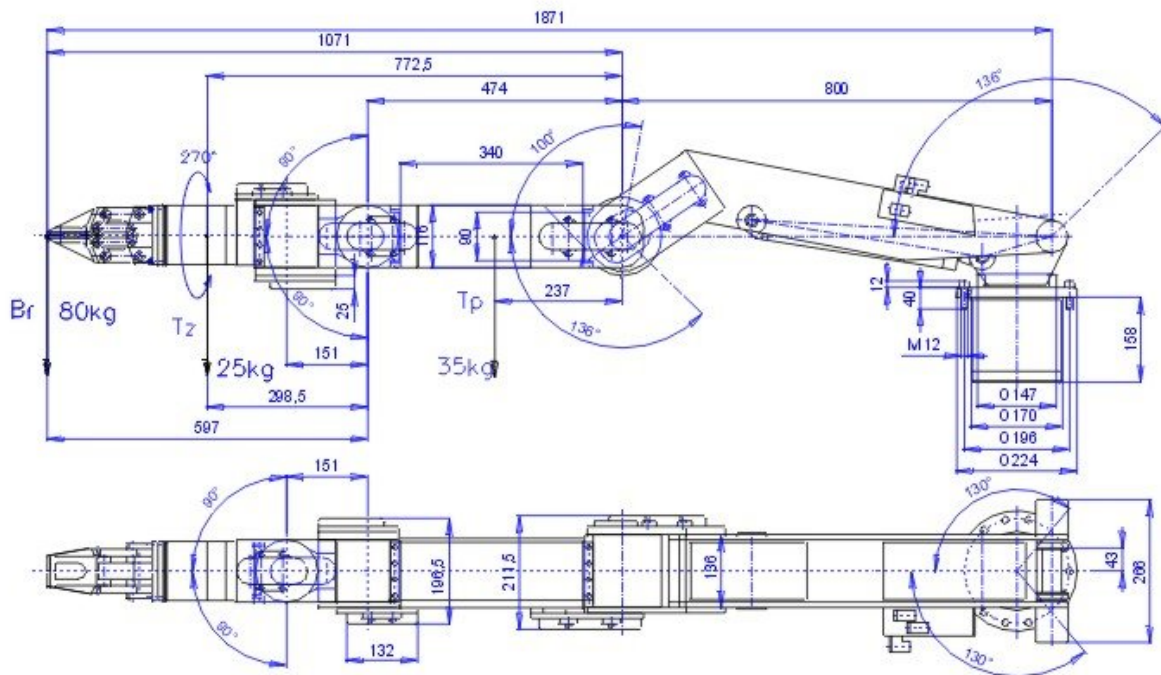


Fig. 1 General Purpose Manipulator MT-80.

The control unit allows to program laborious and repeated tasks, which are often used in decontamination or dismantling procedures. The operation of MT-80 is controlled from the control panel by a pair of joysticks or by the master arm (a miniature kinematics replica of the manipulator arm). The manipulator arm can be controlled in two different modes: the absolute coordinate system or the tool coordinate system. The first mode is used for general manoeuvring of manipulator and the second one for performing specific tasks, which require precise leading of tools (thermal cutting etc.). The base of MT-80 can be fixed to a steady console or when it is required to improve mobility of the manipulator it can be fixed to a telescopic column or supporting construction on the rails.

The mock-up tests of manipulator were done in 2001 and since then the manipulator has been successfully used for many decontamination and dismantling tasks.

MT-80A General Purpose Manipulator

Based on the design of the MT-80, its improved version manipulator MT-80A was developed in 2002. Technical improvements were focused mainly on strengthening of construction and improvement of manipulator reach. Many different special tools, which can be remotely attached to manipulator wrist, were developed too.

The operation software was reprogrammed and enhanced. Improvements allowed drilling and cutting at different angles of tool and more precise movement of the tools according to the tool coordinate system. The manipulator can operate from the same movable platform as MT-80.

The main parameters of MT-80A are as follows:

- shoulder yaw: $\pm 130^\circ$
- shoulder pitch: $+136^\circ$
- elbow pitch from: -136° to $+100^\circ$
- wrist pitch: $\pm 90^\circ$
- wrist yaw: $\pm 90^\circ$
- wrist roll: $\pm 135^\circ$
- reach: 1950 mm
- payload: 80 kg
- weight: 230 kg

Its mock-up tests were successfully done in 2003 and since then the manipulator has been successfully used for different dismantling tasks, one of the examples is dismantling of Heavy water evaporator described below in this paper.

DENAR-41 Long-Reach Manipulator

One of the main priorities of the A1 NPP Decommissioning Project is decontamination and decommissioning of underground storage tanks. For that purpose the special manipulator DENAR-41 has been developed. Large diameter of the storage tanks (up to $\varnothing 16$ m) and small dimension of the inspection chamber hole (540 x 540 mm), through which manipulator can be inserted into tanks, were the main difficulties in the development of manipulator.

DENAR-41 (see Fig. 2) is long-reach hydraulic manipulator fixed to a bearing construction. The bearing construction (1) is placed over a tank thus that its weight does not press on the tank construction. The manipulator consists of a vertical unit (2) with a rotation column (3) and three tilting arms (4). The vertical unit is fixed to the bearing construction and the rotation column is inserted into the tank through the hole in the inspection chamber. The column rotates with arms around its vertical axis ($n \times 360^\circ$). The tilting arms are attached to the bottom part of the column and their kinematics allowed the manipulator to reach any point on the internal surface of the tank. The manipulator arms are hydraulically actuated. The wrist (5) with decontamination tool is attached to the last arm (wrist yaw $\pm 90^\circ$ and wrist pitch $\pm 30^\circ$).

The bearing construction and the tilting arms are modular type, because of different diameter of storage tanks ($\varnothing 16$ m and $\varnothing 6$ m). In case of large tanks the reach of manipulator is 9 m (the first set of the tilting arms) and payload at full extension is 35 kg. For smaller tanks the reach of manipulator is 6.15 m (the second set of the tilting arms) and payload at full extension is 50 kg. In this case it is possible mounted manipulator MT-80 instead of the last tilting arm. This configuration is applied for decontamination of tanks with complicated geometry or tanks containing technological equipment (piping).

The wrist of manipulator can be equipped with different tools for decontamination, dismantling and waste retrieval. Two cameras (6) are used for in-tank views of the DENAR-41 operation and its manoeuvring. The first camera is mounted to forearm to observe operation of the decontamination head. The second one is mounted on its own

tilting arm to make better perspective view of the tool. This camera has a built-in light, a panoramic self-driven head and its own control unit.

The manipulator is controlled from the operator cabin through the set of joysticks. If DENAR-41 bears the manipulator MT-80 the separate control unit of MT-80 is also placed in the operator cabin. When operating MT-80 the DENAR-41 control unit is blocked and vice versa.

The main parameters of manipulator DENAR-41 are as follows:

- column rotation: 360°
- arm 1 yaw: ± 60°
- arm 2 yaw: ± 90°
- arm 3 yaw: ± 90°
- wrist rotation: 90
- wrist yaw: ± 90°
- wrist pitch: ± 30°
- reach: 6 500 or 9 000 mm
- payload: 50 or 35 kg
- weight of manipulator: 2 670, 2780 or 3 200 kg
- weight of bearing construction: approx. 11 000 kg

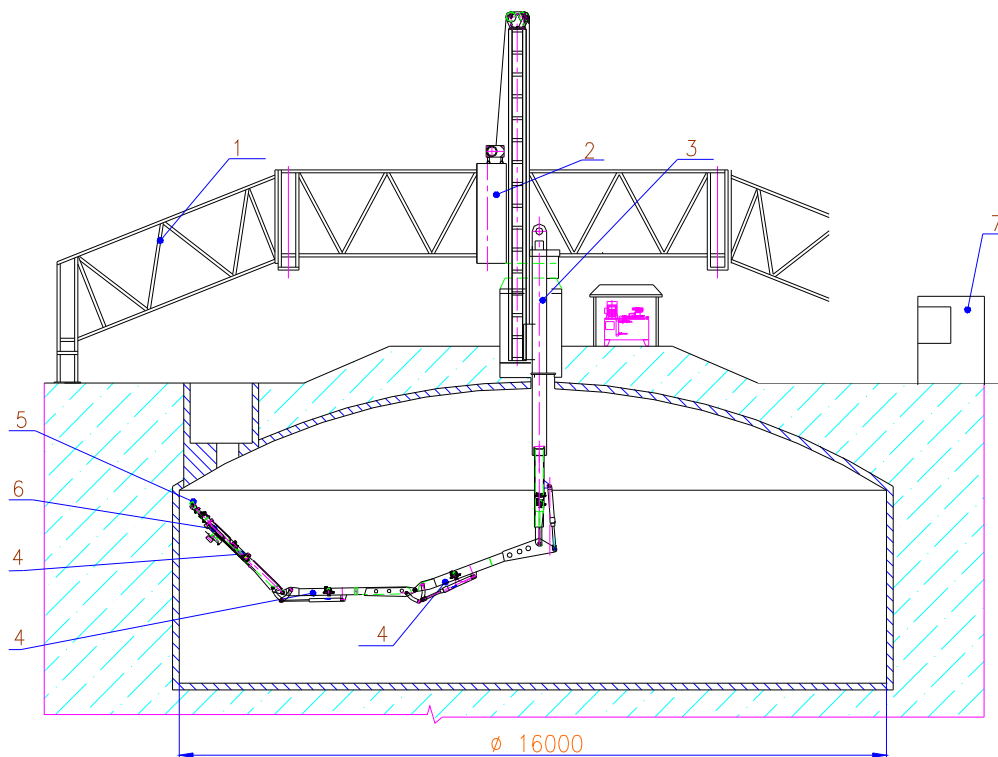


Fig. 2 Long-Reach Manipulator DENAR-41.

Manipulator mock-up tests were done in 2001. Since then, the manipulator has been successfully used to decontaminate six underground storage tanks. The manipulator has been also used for pipe cutting, cutting of tank surface coating layer (PESL – polyester glass reinforced laminate) and high-pressure rinsing of surfaces. The manipulator has been used for pumping the radioactive sludge off from the bottom of the storage tank. The sludge has been treated in the movable cementation facility, developed for this purpose.

Remotely Controlled Tool Carrier

The Remotely Controlled Tool Carrier (RCTC, or so called “sludge walker”, Fig. 3) has been developed for tasks related to retrieval of wet radioactive waste from the storage underground tanks of A1 NPP. The RCTC is a mobile robot designed for carrying of tools and equipment. It can carry a set of auxiliary exchangeable tools for disrupting, loading and removing of sand, gravel and sediment, and pumping off liquid sludge.

The vehicle consists of a mobile chassis to which four electrical gearing boxes of wheels are fixed. Independent electrical motors drive the stainless wheels so manipulator can move in any direction. Thereby it is also possible to make a 360° turn of RCTC on place around its vertical axis. There is a platform on the chassis on which a membrane pump or a sludge pump or an auxiliary container can be fixed. A rotating arm is fixed to the front part of the vehicle. A shovel is fixed to the arm and furthermore a rotating brush or rotating saw-tooth cutter can be provided too. The brush and cutter are driven by independent electrical motors. The rotating brush or cutter sweeps sludge or gravel to the shovel and by turning the arm waste is poured into the auxiliary container. When the container is full it is withdrawn by auxiliary raising equipment and emptied to 200 l drum. All components of robot are made of stainless steel.

The Remotely Controlled Tool Carrier has a hanger on the rear part, which is used for inserting robot into a tank or lifting it out of a tank. The RCTC is inserted vertically to a tank with liquid RAW by means of an inserting device. After contact of the carrier wheels with the bottom of a tank, the wheels start turning slightly forward and the carrier is being stabilised concurrently with its lowering.

Electric parts of the Remotely Controlled Tool Carrier and the auxiliary tools have coverage that allows them to work in the submerged area as deep as 1 m. The RCTC can operate in radioactive environment with specific volume activity up to 10^7 Bq.dm⁻³ and it can be decontaminated.

The RCTC is controlled from a control panel, where all control elements for the carrier, the auxiliary tools, the inserting device and the container-lifting device are located. The carrier is monitored through the camera system consisting of two cameras. One of them is fixed to the bearing construction that consists of a vertical column and an arm that can be inserted into a tank. The second camera is mounted on the top part of a tank, close to the lifting device.

The main parameters of Remotely Controlled Tool Carrier are as follows:

- total width: 550 mm
- total height: 550 mm

- total length with sweep device: 1303 mm
- length of carrier: 840 mm
- shovel width: 460 mm
- shovel volume: 12 dm³
- auxiliary container volume: 43 dm³
- overall power consumption: 2 kW
- carrier speed: up to 0.3 m.s⁻¹
- weight of carrier: 130 kg

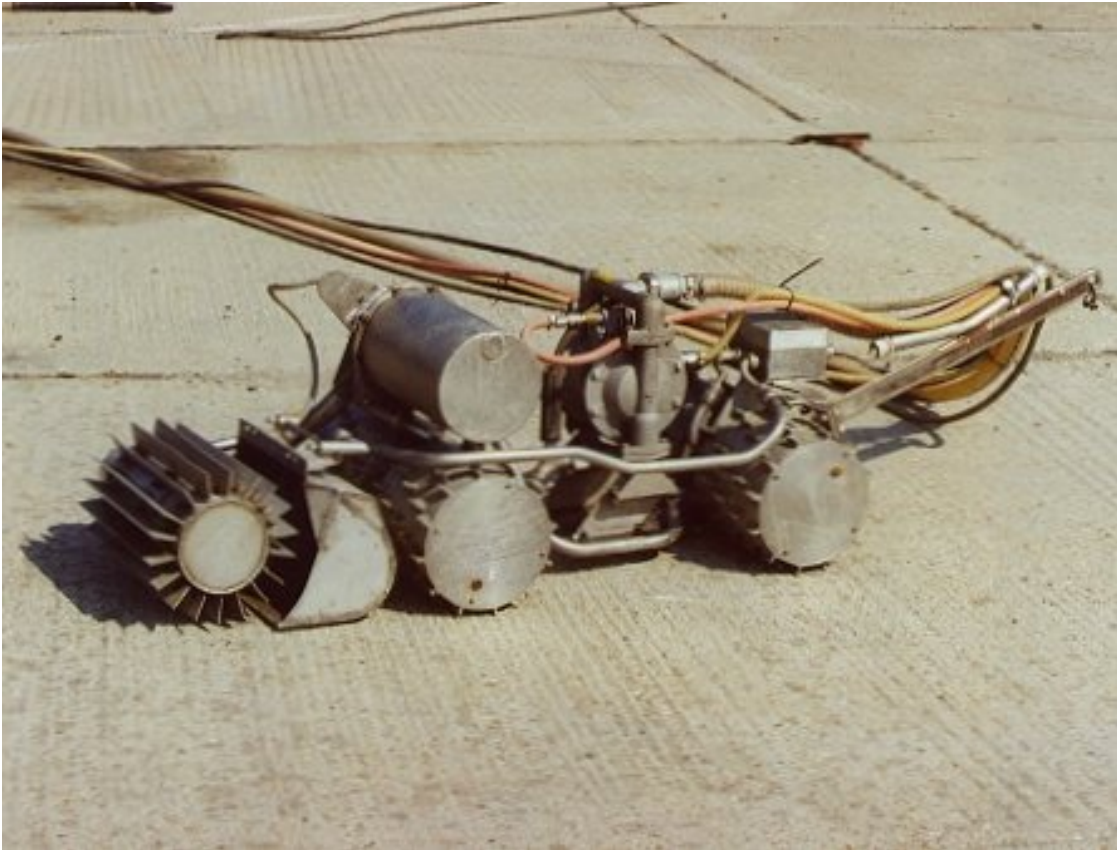


Fig. 3. Remotely Controlled Tool Carrier (“sludge walker”) equipped with the sweep device, the shovel and the membrane pump.

The RCTC was tested in 1998-1999 and since 2000 it has been successfully used for treatment of liquid sludge from the underground storage tanks of A1 NPP. About 30 m³ of sludge and gravel and 60 m³ of liquid radioactive waste have been retrieved from two underground tanks during several hundreds of working hours of vehicle.

HEAVY WATER EVAPORATOR DECOMMISSIONING

Evaporator facility description

The heavy water handling system, as one of the A1 NPP nuclear auxiliary systems, ensured storage, cooling, refilling of moderator into the reactor core and heavy water leakage collection. Purified heavy water from an evaporator flowed into a handling tank of the moderator refilling system.

The heavy water evaporator facility consists of two identical mirror-oriented evaporator loops located in the main production unit building. Each loop includes an evaporator, a separator, a condenser and connecting pipes. Common apparatuses are a degasser, a condensate tank, a washing pump, a oil filter and an air pump. The main functions of the heavy water evaporator facility were:

- continual heavy water purification, disposal of the corrosion products,
- heavy water retrieval from liquid radwaste produced by CO₂ cleaning system,
- heavy water leakage purification which was collected from the heavy water handling system equipments.

From the hot collector of circulating moderator system heavy water was fed into the degasser, where CO₂ was separated, then flowed into the evaporator. Heavy water vapour was conducted through droplets separator to the condenser. The condensate flowed into the handling tank of the moderator refilling system. Released CO₂ from degasser and the condenser was transferred to the cold traps where D₂O vapour was freeze-dried. Finally concentrated rest inside the evaporator was burned-out by the electric stove.

The heavy water facility is situated in the main production unit building. One evaporator is installed in the room No. 220 and another one in the room No. 219. The other technological apparatuses are installed in the next rooms. The dose rate inside the room No. 220 was max 0.270 mGy/h (19 mGy/h compared to the room No. 219) and the surface contamination was max 8,5 Bq/cm². Loose surface contamination of inner surface of evaporator installed in the room No. 220 was 1.28x10³ Bq/cm² and dose rate inside the equipment was 1.5 mGy/h. Dominant radioisotopes were Cs-137, Co-60 while Am-241 rate is minor.

Technical equipment used for decommissioning

Due to the high level of contamination it was decided that the evaporator facility will be dismantled remotely. After analysing required dismantling and decontamination tasks, disposition of apparatuses, piping, and access to the evaporator rooms, manipulator MT-80A was chosen as a suitable device for intended operations. Its basic mechanical and kinematical parameters are described above.

However, certain modifications have been done to improve its mobility and accessibility. It has been designed movable supporting constriction with tilting arm, to which manipulator is fixed. This solution allows easy installation of manipulator to working

position inside the evaporator room and the tilting arm considerably extends reach of manipulator from one working position.

Resulting from different required task to be performed existing tools for manipulator have been modified and certain new tools have been designed. It was required that tools could be exchanged remotely. Therefore the tool connection head, which is attached to the wrist of manipulator, has been designed. It is equipped with centring pins and hydraulic lock, which are used for fixing of tools. Quick connectors for providing tools with working media (electric power, hydraulic oil and control signals) are mounted on the body of the connection head. All tools have been modified that they could be clamped to the tool connection head remotely. Two boxes for storing tools have been designed too. The tools have been modified for quick remote changing. The following tools were used during dismantling the evaporator facility:

The **handling effector** is used for collecting of clippings fallen down on the floor during fragmentation. It consists of a handle in a form of a bar with a blade and an adapter for attaching it to the tool connection head of MT-80 manipulator.

The **hydraulic shears** are modification of industrial hydraulic shears used for demolition and rescue operations. They are used for cutting steel, cables and tough non-ferrous materials. The shears are fixed to a holder which is adjusted for clamping to the tool connection head of MT-80 manipulator.

Basic technical parameters:

cutting force: 552 kN at pressure 500 bar
blade span: 279 mm

The **reciprocating saw** is used for cutting pipes up to 100 mm in diameter. It is also modified industrial tool electrically powered. It is fixed to a special holder that allows it to be connected with the tool connection head of MT-80 manipulator.

Basic technical parameters:

power consumption: 1400 W
saw blade length: 250 mm

The **electromagnetic effector** is used for collecting of clippings from ferro-magnetic materials which are produced during fragmentation.

The **circular saw** is used for fragmentation of the evaporator walls. It can cut metal sheets up to 30 mm in thickness. It is modified industrial product electrically powered and equipped with a holder, which enables it to be clamped to the tool connection head of MT-80 manipulator.

Basic technical parameters:

power consumption: 1200 W
diameter of saw blade: 230 mm

The **sampling device** is used for taking samples from places with difficult access inside the tubes. The tool has two blades in the front part. The blades make a linear motion, thus opening or closing the space between them for depositing sample. The motion of

the blades is electrically powered. The rear part of the holder enables it to be clamped to the tool connection head of MT-80 manipulator.

Technological procedure applied for decommissioning

The heavy water evaporator facility decommissioning started in 2010. The evaporator equipment situated inside the room No. 220 was chosen to be decommissioned as the first one due to better radiation situation. Gained experience from the room No. 220 will be utilized in the decommissioning of the next door room No. 219. The other apparatuses (the separator, the condenser, the degasser, etc.) will be decommissioned as the last one.

Preparatory Work

Prior to start of dismantling works, with special focus on the elimination of activity and aerosols leaking into the environment, the evaporator, all relevant pipes and impulse pipes had to be drained. Samples of 100 ml liquid radioactive waste with sludge were taken from the evaporator. Sample analysis proved necessity of pre-disassembly decontamination. The activity of samples was as follows:

- total gamma activity of liquid phase 6.23×10^7 Bq/dm³, alpha activity Am-241 1.33×10^3 Bq/dm³, tritium activity 9.37×10^9 Bq/dm³,
- total gamma activity of sludge phase 4.09×10^7 Bq/dm³, alpha activity Am-241 9.19×10^4 Bq/dm³.

Internal surface of the pipes and evaporator body were drained, rinsed and dried. Twelve 60 dm³ drums of liquid radwaste were produced and stored for further treatment at Bohunice RAW treatment centre.

A technological opening with dimensions approx. w x h (1200 x 1500 mm) has been made into the 1200 mm thick wall between the corridor (the room No. 229) and the room No. 220. The shielding door has been installed to cover the technological opening. The thickness of the door was calculated by using the VISIPLAN programme: for the room No. 220 – 20 mm steel shielding, for the room No. 219 – 100 mm steel shielding. Furthermore, two additional observing openings were made in the wall for the camera monitoring system. The diameter of observing openings is approx. 200 mm and they are made symmetrically to the room axis at the high approx. 1800 mm. The distance between them is 1800 mm.

A lightweight portable containment made from profiles and PVC foil has been built in front of the technological opening. The containment and also the room No. 220 are ventilated with a portable exhaustion device with built-in HEPA filter. Its exhaust is connected to the existing ventilation system. Then all units of the manipulator has been transported to the work space, connected, reactivated and tested.

Evaporator Dismantling and Fragmentation

An obstacle which limited the manoeuvring possibilities of the manipulator in the area had to be fragmented as the first. Those obstacles were the connecting rods for distant control of armatures and piping between the evaporator and the technological opening.

Prior to fragmentation of the drained piping it was necessary to check activity inside of them in order to decide about the subsequent decontamination and handling of the fragments. Then the pipes were cut to pieces with approx. 400 mm length by the reciprocating saw. Some pipes were cut by hydraulic shears.

When the connecting rods and pipes were removed from the space between the technological opening and the evaporator dismantling and fragmentation of the evaporator began in the following order:

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



Fig. 4. Dismantling of the evaporator by MT80A manipulator.

When fragmentation tasks will be finished and all the fragments, the MT-80 and the mobile truck will be removed from the room, the following tasks will be performed:

- building-up the technological opening,
- removal of the technological opening shielding,
- removal of the containment,
- decontamination of the room No. 220 and corridor No. 229.

CONCLUSIONS

Presented manipulators have been designed for broad range of decommissioning tasks. They are used for recognition, sampling, waste retrieval from large underground tanks, decontamination and dismantling of technological equipments. Each of the mentioned fields claims specific requirements on design of manipulator, their operation and control systems as well as tools of manipulators. Precise planning of decontamination and dismantling tasks is necessary for its successful performance by remotely controlled manipulator.

The example of the heavy water evaporator demonstrates typical procedure for decommissioning of contaminated technological equipment by remotely controlled manipulators - planning of decommissioning tasks, preparatory tasks, modification of applied tools and design of specific supporting constructions for manipulator and finally decontamination and dismantling themselves.

Due to the particularly demanding conditions in highly contaminated A1 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 environment with a high radiation level has been developed.

REFERENCES

1. J. Medved, L. Vargovcik, "Decommissioning of the A1 NPP Heavy Water Evaporator Facility" ICEM Conference, Reims, France (2011).
2. K. Kravarik, V. Michal, "Technology Development for Decommissioning in Nuclear Power Plants research Institute, Slovak Republic. ANS Robotics and Remote Systems Meeting, Seattle, USA, March 2001.
3. State of the Art Technology for Decontamination and Dismantling of Nuclear Facilities. Technical Reports Series, No. 395, Vienna, Austria, 1999, International Atomic Energy Agency (2000).
4. M. Tanaka, M. Takeo, T. Hirabayashi and S. Yanagihara, "Decommissioning programs and Technology Development in Japan Atomic Energy Institute" WM'99 Conference, Tucson, Arizona, USA (1999).
5. B. L. Burks, D. D. Falter, R. L. Glassell, S. D. Van Hoesen, M. A. Johnson, P. D. Lloyd and J. D. Randolph, "A Remotely Operated Tank Waste Retrieval System for ORNL", REDWASRE, (March 1997).