MOVABLE CEMENTATION FACILITY FOR FIXATION OF RADIOACTIVE SLUDGE IN DRUMS

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ABSTRACT

Presented paper describes Movable Cementation Facility (MCF) developed for fixation of radioactive liquid waste in 200 l drums.

There is shortly described the most important ongoing decommissioning project of A-1 NPP in the Slovak Republic. One part of this project is a treatment with Liquid Radioactive Waste and sludge to minimize their eventual impact on environment.

Radioactive sludge is stored in large underground storage tanks at A-1 NPP or other NPPs operating in the Slovak Republic. Due to their various kinds of origin they have different chemical, physical and radiological composition and different level of activity. Furthermore, they very often represent so-called historical waste with unknown properties.

The developed MCF allows waste immobilization in different kinds of inorganic matrixes. It has employed in drum mixing and thus the final product is waste fixed in stable matrix stored in 200 l drums. The technological flow sheet of process is presented in this paper. MCF employs these main operation steps:

- pumping of sludge from underground storage tanks into the operation tank, and its sampling and analyzing,
- sedimentation of sludge, separation of sludge and aqueous phase and estimation of appropriate composition of fixation matrix for sludge phase,
- dosing of sludge and other components of fixation matrix according to the prescribed formulation, in drum mixing of component of matrix,
- vibration/compaction of drum content, taking samples of final matrix product,
- matrix curing, drums lidding, measurement of dose rate on produced drums and their expedition,
- overall dose rate and concentration of aerosols in operation area,
- decontamination of apparatuses, which are in contact with active media.

MCF was developed as a movable facility, which can be easily transported and built up near any tank with stored and treated sludge. Main technological apparatuses are

mounted in four ISO containers, which are provided with autonomous ventilation and filtration system. The whole process is remote controlled from the control desk placed in a separate container. This configuration allows treating of sludge with relatively high activity. MCF is designed that as the maximum final dose rate on surface of drums with immobilized sludge can reach up to 30 mGy/hour. The dimensions and performance of main installed apparatuses such as separation tank, dosing unit, mixer, and lidding unit are described in this paper.

The design and manufacture of MCF was done in 2003 and 2004. Extensive mock-up testing of facility was performed in 2004. The simulated sludge was used in these tests and obtained results are presented. The tests focused on reliability and performance of facility. Sufficient results were obtained, however several alternation in design were done to optimize facility performance. Obtained experiences are discussed in this paper. MCF is planned to put in operation with active sludge at A-1 NPP Jaslovske Bohunice by the end of 2004.

In conclusion, experience with operation of MCF in non active conditions is described as well as future deployment of facility in decommissioning activity in Slovakia.

INTRODUCTION

Nowadays there are 6 units in operation in the Slovak Republic (1^{st} and 2^{nd} unit V-1, 1^{st} and 2^{nd} unit V -2 at Jaslovske Bohunice NPP and 1^{st} and 2^{nd} unit at Mochovce NPP), 2 units are under temporary stopped construction (3^{rd} and 4^{th} unit at Mochovce NPP). All mentioned reactors are of Russian design WWER-440, type V-230 and V-213.

The first NPP operated in Slovakia was A-1 NPP Jaslovske Bohunice. Its reactor unit was provided with reactor cooled by CO_2, moderated by heavy water and natural uranium was used as its fuel (HWGCR type). It was in operation since 1972 and was finally shutdown in 1977 after an accident (level 4 according to the International Nuclear Event Scale). The reactor unit is in the preparation stage for decommissioning of its components. Some auxiliary buildings have already been decommissioned to the green field. The part of turbine buildings is used for processing and storage of radioactive waste. All spent fuel from A- 1 NPP has been transported to Russia. Low level and intermediate radioactive waste from the main production unit has been partially treated and conditioned.

VUJE has been chosen as a general supplier for the A-1 NPP Decommissioning Project. The important part of the A -1 NPP Decommissioning project is a treatment of radioactive sludge stored in underground storage tanks at A -1 NPP.

Initial Status Description

Underground Tanks Description

The underground tanks were built in sixties. Two of them are built of concrete panels with monolith arched ceiling. Waterproof plaster and Polyester Coating (PESL) finished the inner surface. The outside surface of the tanks is insulated by asphaltboard. Diameters of the tanks are 16 m and theirs highs are 6.4 m. The dimensions of entrance chambers are 1600 x 1600 mm, their surface is stainless steel bonded, and the dimensions of manholes are 575 x 575 mm. The other two tanks are welded from steel sheet with thickness of 2.5 mm stocked to the basic concrete-iron construction. Diameters of the tanks are 11.5 m and their height is 4 m. The dimensions of entrance chambers are 1600 x 1600 mm and the dimensions of manholes are 580 x 580 mm.

Sludge Characterization

The overall amount of sludge is about 200 m^3. It has been produced during operation of A-1 NPP or was produced after an accident of A-1 NPP as a result of a treatment of high active water by means of potash ferrocyanide and copper sulphate.

There have been several times taken samples and they have been analyzed at VUJE laboratory. The basic chemical and radionuclide composition has been analyzed. Physical and mechanical properties have been determined too. The results of analyses can be summarized as follows:

There is a dominant amount of iron and calcite, which are probably in the form of oxo – hydroxides. The solid phase consists of composition of magnesium, manganese, chrome, aluminium and silicium. The amount of dry phase is about 10% of mass. Aqueous phase contains the sulphates, chlorides, phosphoresces, alkali nitrate and hydrogen carbons.

The results of distribution of particles show that the predominate part of particles is from 1 to 10 μm. Their density ranges from 2.0 to 2.9 g/cm^3. It is supposed that the concentration of solid particles in gravity field should be from 15 to 20% of mass. The dynamic viscosity of sludge with 15% concentration of dry residue reaches 9 mPas.

Sludge contains a significant amount of alpha nuclides. The activity of Pu^{238}, $Pu^{239+240}$, Am^{241} in dry residue reaches 10^5 to 10^6 Bq/kg. The activity of Cs^{137} ranges from 1.10^9 to 6.10^9 Bq/kg and the activity of Co^{60} ranges from 3.10^6 to 2.10^8 Bq/kg in dry residue of sludge.

Generally sludge is non homogenous, with very adhesive properties and with great specific activity. The existing treatment facility in Slovakia is not able to treat this kind of waste because of its technical and safety limits. Therefore a new facility for treatment of such waste has been developed, designed and constructed. Results of laboratory fixation of sludge into different fixation matrixes, experiences with retrieving of sludge from underground tanks and VUJE experience with cementation in 200 l drums was utilized there. Thus Movable Cementation Facility, which can be installed near any tank with treated radioactive waste, has been designed.

Movable Cementation Facility

Technology Principle

Radioactive sludge is fixed in a cement matrix directly in 200l drums. The Mobile Cementation Facility (MCF) employed the batch procedure. The formulation of cement grout is based on demand of quality of final product (strength of cement product, leachability of radionuclides, limited content of radiouclides in cement product and dose rate on surface of drums).

The drums with cemented sludge are processing at Bohunice Treatment Centre (BTC). The drums are loaded into Fibre Reinforced Concrete Containers (FCC) and fixed with cement grout prepared from cement and radioactive concentrates. The FCCs are stored in National Republic Repository in Mochovce.

Movable Cementation Facility Design

All component of the MCF (See Fig. No. 1) are placed in four ISO containers, which serve as transport means. The MCF is designed for production of drum with overall activity 1.10^{11} Bq. The MCF is connected to existing system of electricity, distribution system of demineralized water and ducting system. However the MCF has its autonomous ventilation system and source of pressed air. In Fig. No. 1 connection of MCF to Active Water Purification Station of A1-NPP is shown.

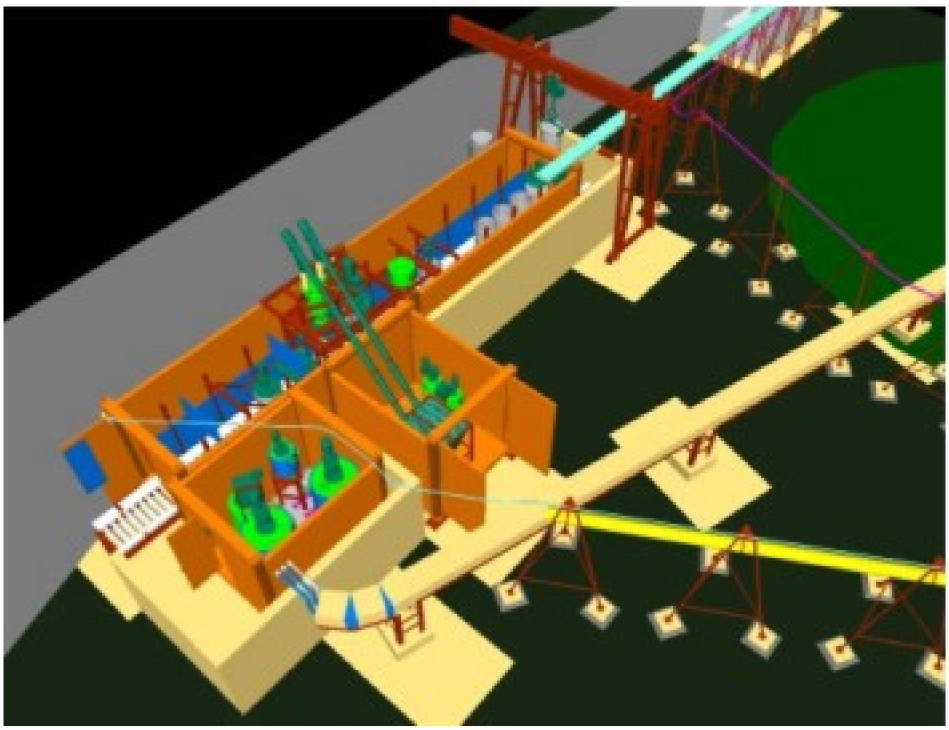

Fig. 1. Model of the MCF and its connection to Active Water Purification Station of A1-NPP

Radioactive sludge is pumped from underground tanks by the sludge pump, which is supported by the arm of DENAR manipulator. The DENAR manipulator can maneuver the sludge pump over the whole bottom surface of the tank. The sludge is pumped into MCF through the pipe placed in a safety concrete canal. The concrete canal is sloped into to the underground tanks for safety reasons. There are pipes for washing water, transport water and accident water placed too.

The MCF is remote operated from control unit. The produced drums are loaded into shielded transport container by crane, which is a part of the MCF. Concrete panels surrounding the facility shield the whole facility.

Disposition of the facility is shown in Fig. No. 2. The receiving, homogenization and sedimentation tank are placed in the first container (KI). The process tank, weighting unit, pump of sludge, pump of aqueous phase, pump of decontamination solutions, sampling box, draining tray are placed in this container too. The sampling box of sludge is manhandled from container’s outside. All equipments with active materials are shielded.

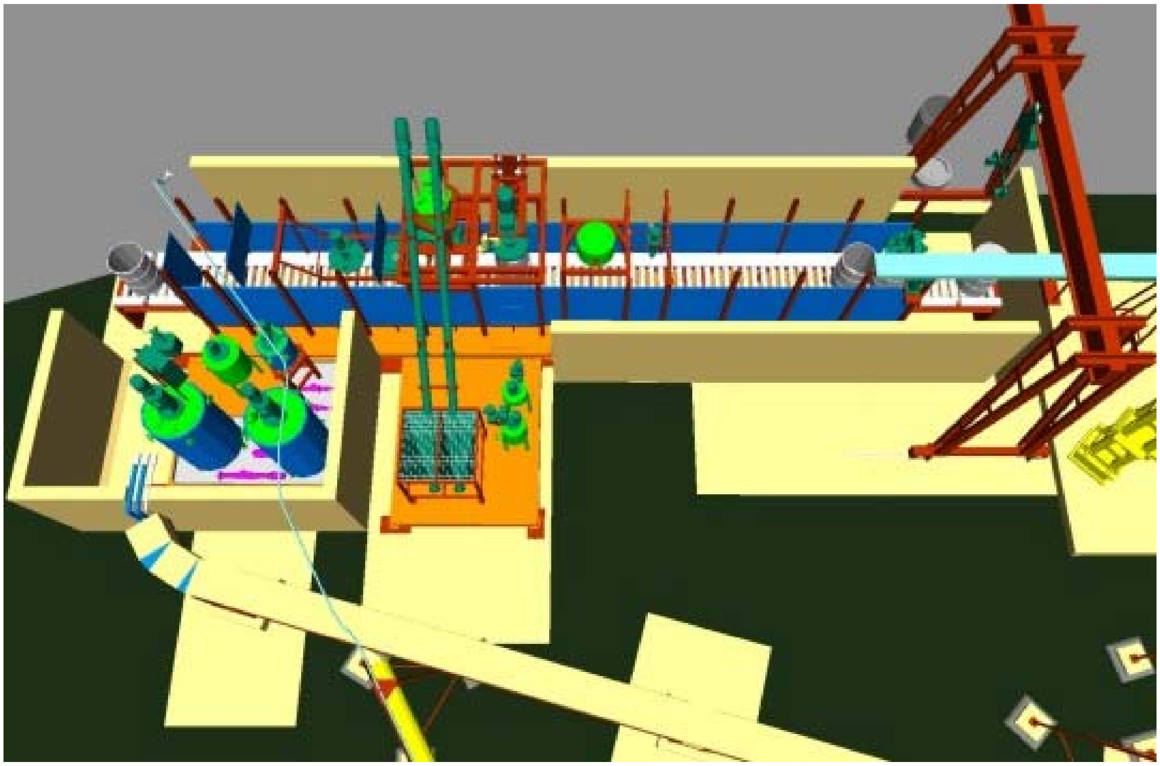

Fig. 2. Disposition of technological component of the MCF

The second container is dedicated to non-active equipment such as bins for cement or other powder materials, their screwdrivers, two tanks of aqueous additives and their dosing pumps and the compressor. The ventilation system with HEPA filter is placed on the top of the container.

The container No. III and No. IV are designed for processing of drums with waste. Roller conveyors, dosing lid of drums, weighting unit of powder materials, homogenization unit, vibration plate, sampling equipment of cement product, mechanism for placement and fixation of lids on drums are placed there. Draining tray is placed under the roller conveyers. The shielding along the roller conveyors is provided from lead tin plates. The end parts of conveyers can be tilted inside the container during their transportation.

The ventilation unit provides ventilation of the whole space of ISO containers, ventilation of receiving tanks of sludge and the drums in position of filling and homogenization. All equipment, which is ventilated, is provided with aerosol filters. The ventilation unit is equipped with a bag and HEPA filters. The regulation of underpressure is provided by slide valve on ducts of ventilation system.

The radiation control of MCF includes operators radiation control, area radiation control of containers and outlets from containers.

The Description of Technological Flowsheet

The technological flowsheet is shown in Fig. No. 3. Sludge is pumped from underground tanks into receiving homogenization tank (position 1a). The amount of pumped sludge is controlled by sludge level measurement in the tank and radiation rate measurement on the tank surface. The content of the tank is homogenized by mixing paddles and with circulation provided by circulation pump C1a. Sample of sludge is taken from sampling box (Pos. 39), which is mounted on circulation bypass. The ratio of dry residue in sludge is estimated and chemical and radionuclid analysis are done. On the basis of these analysis fixation formulation is suggested – ratio of dry residue, amount of batch water and fixation matrixes in the way that dose rate on the surface of drum and the amount of important radionuclids in 200 l drums do not exceed limits for loading of products into Fibre reinforced Concrete Containers.

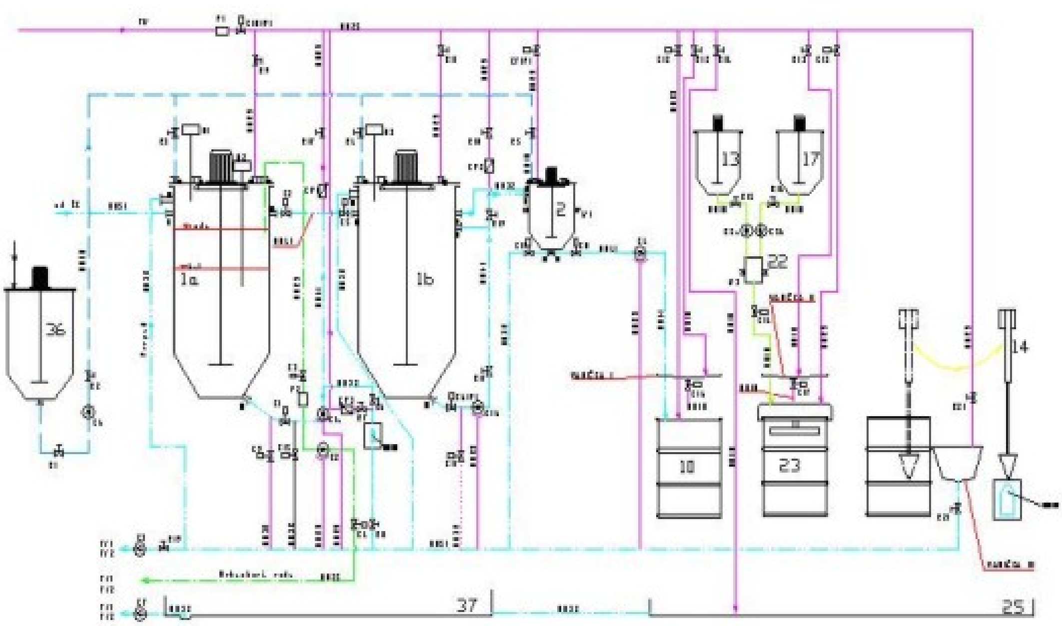

Fig. 3. Technological flowsheet of the MCF

The sludge in receiving tanks is then sedimented and surplus water is pumped back into underground tank. The interface between the aqueous and the dry residue is measured optically and the pipe of decanting pump C2 is automatically immersed above that interface. Decanting and pumping of aqueous phase is stopped when the ratio of dry residue and batch water is reached according to the prescribed formulation. The sludge is then pumped from the receiving tank (Pos. 1a) into the operation tank (Pos. 1b). The receiving tank is then used for preparation of next batch of sludge.

On the beginning of the roller conveyer, there are placed two 200 l drums. The first drum is moved to the position of dosing of sludge (Pos. 10). The filling lid is fixed on the drum by raising mechanism. Sludge is pumped from the operation tank (Pos. 1b), which is continuously homogenized with mixing paddles, into measuring bin of sludge (Pos. 2) by the pump C1b. The measuring bin is homogenized too and the appropriate amount of dosed sludge is controlled by measurement of its weight. Sludge is dosed to the drum by pump C4 through filling lid of the drum.

The drum with sludge is moved to the position of mixing (Pos. 23). The draining try (Pos. 11) is plugged under the filling lid and also the second - washing drum is moved under the filling lid of sludge (Pos.10). The measured amount of water is used for cleaning of the lid. Water is collected in the washing drum.

The mixing lid is then attached to the drum with sludge and the drum is fixed in the mixing position. The lid has flexible connection to dosed powder matrix and aqueous additives. Powder matrix is conveyed to weighting unit (Pos.2) by screw conveyer and dosed to the drum by vibration feeder (Pos. 29). Aqueous additive is pumped into the drum. Spatial mixing units provide homogenization of the drum content. Its blades are rotating in drum and the shaft of mixer is also moving up and down in the drum in vertical direction. When the homogeneity is reached the mixing lid is moved to upper position and drainage tray II (Pos. 44) is plugged under the lid. The drum with cemented product is moved to the position of its compaction (Pos. 15) and sample taking. The drum is lifted over the roller conveyer by air lifting bags and vibrates to achieve better rate of compaction. The sample of cement product is taken by remote controlled sampling device into shielded sampling pot. Afterwards the drum with cement product is moved to the solidification position on the conveyer, where four drums can be stored.

The washing drum is moved under homogenization unit and mixing lid is attached to it. The amount of washing water for cleaning of mixing lid and mixer is measured and collected in washing drum. The sampling device is washed too. The washing drum is then by reverse moving of conveyer returned to its begining. In front of this drum, there is placed a new drum for filling with sludge.

The washing water is pumped into underground tanks or is used as a batch water for cementation after solidification of cement phase.

The drum with cement product is moved to the lidding position (Pos. 36). Liding is provided remotely by pneumatic device. The drum is then placed by crane, which is part of the MCF, into shielded container and transported to Jaslovske Bohunice Tratment Centre. The drums are placed to Fibre Reinforced Concrete Containers, cementated and stored at Mochovce National Repository.

The Control of MCF

The control of the MCF is possible in two modes. It is possible to operate it in manual mode by controlling each step of technological process from control desk or in automatic mode, when computer controls the whole procedure. All parameters of process are recorded. The operators of the MCF enter into the containers with technological components only to add powder matrix materials into their storage bins, to add aqueous additives to their storage tanks, to take samples of cement product and to put the lid on drums. Shielded walls along the whole production line protect operators. All other operations are provided remotely. Specific operations (putting of the sludge lid on the drum, homogenization, taking of cement samples and lidding of drums) are observed via implemented camera system.

Radiation Control and Protection

Personal radiation control is organized through the nearest stationary dosimetric equipment in the control loop of Gas Production Building. Obtained dose rate is measured on personal dosimeters, which are assigning to the operator on entering the control area. Furthermore the portable monitor of contamination of hands/feet is placed in the control room of the MCF.

The radiation control of working areas includes:

- measurement of dose rate in all areas with technological components by build-in detectors,
- measurement of volume activity of air in container by taking samples of air or α and β activity is measured on samples of aerosols captured on sampling filters,
- contamination of walls and floors is measured with portable equipment and on swabbing samples,
- balance measurement of activity outlets of the MCF,
- filtration system efficiency control.

Radiation control system is connected to control PC placed in control unit of MCF. The chosen dosimetric information is transmitted by radio connection to the control room of Gas Production Building.

The Main Technological Equipment Parameters

Receiving and Homogenization Tank (Pos. 1a)

material :	stainless steal
volume :	1 m^3
diameter :	ϕ 900 mm
height :	1800 mm
shielding :	circumference of the tank: removable lead sheet with 35 mm thickness
	lid of the tank: removable lead sheet with 10 mm thickness
accessories :	mixing blades – input power 1,5 kW
	maximum level probe
	dose rate probe
	equipment for measurement level of aqueous phase and dry residue phase

Operation Tank (Pos. 1b)

material :	stainless steel

volume :	1 m^3
diameter :	ϕ 900 mm
height :	1800 mm
shielding :	circumference of the tank: removable lead sheet with 35 mm thickness
	lid of the tank: removable lead sheet with 10 mm thickness
accessories :	mixing blades – input power 1,5 kW
	continuous measurement of sludge level

Sludge Measuring Bin (Pos. 2)

material :	stainless steal
volume :	0,075 m^3
diameter :	ϕ 400 mm
height :	610 mm
shielding :	circumference of the tank: removable lead sheet with 35 mm thickness
	lid of the tank: removable lead sheet with 10 mm thickness
accessories :	mixing blades – input power 0,5 kW
	3 tensometric sensor for measurement of weight of sludge

Pumps of Sludge C1a, C1b, C3, C4

Type:	single screw pumps EPR-40-6-LC-00-9
Output:	Q = 0,5 dm^3/s
Maximum pressure:	0,2 MPa
Electromotor:	0.55 kW, 380 V with frequency regulation
Material:	cast iron, screws are made of stainless steel

Mixing Unit (Pos. 12)

Construction:	supporting construction with sliding
	raising mechanisms
	rotor with blades
	drums fixation mechanisms
	lid with nozzles for dosing powder matrix and aqueous additive
	mixer input power: 3,5 kW
	lifting mechanisms input power 0.55 kW
	maximum lift height: 1200 mm

Lidding Equipment (Pos. 38)

Construction:	arm with circuit plate with lidding pneumatic cylinders
	motor: 2.5 kW
	pressure of air: 0.6 MPa

Crane for Loading of Drums into Transport Container

Crane load:	1000kg
Crane width:	5 m
Maximum lifting height:	3 m

Equipment: hanger for manipulation with drums, camera

Production of the MCF

The operation of the MCF is limited by following factors:

- *Climatic condition*: the MCF is in operation from April to October (28 weeks)
- *Safety factors*: personal protection of operators and surrounding objects and workers
- *Technological aspects*: amount of dry residue in sludge, sedimentation velocity of sludge particles, samples taking and their analyzing, time of cement solidification
- *Operation of Jaslovske Bohunice Treatment Centre*: produced drums are placed into Fibre reinforced Concrete Containers immediately without their storing.

Mock Up Testing of the MCF

The all equipment was mounted in ISO containers and connected with control unit. The simulated sludge was used for experiments. Its physical and mechanical properties were the same as properties of real sludge. The sludge was fixed to cement matrix with adding zeolit and aqueous plastificator. Steps of procedure from homogenization to lidding of cementated waste in drums were tested in the manual mode. The homogeneity of cement product was tested by sampling colour and checked on cut drums with solidified cement product. On the basis of mockup testing severe construction and process changes were realized. The shape of mixer’s blades was changed as well as washing system of filling lid and blades of mixer were modified. The procedure of cement and additive dosing was optimized.

After the muck up test the containers and control unit were transported to A-1 NPP and installed near the underground storage tank (See Fig. No. 4). Connections of the MCF to outside systems were done (outside piping of sludge, water, connection to electric distribution system and dosimetry system). Although the ventilation unit has its own HEPA filter its outlet duct was connected to existing ventilation ducts. Lifting crane for handling with cemented drums was built next to the MCF.

The complete non active testing of the MCF was realized in October. The control system of the process was optimized for existing configuration and the MCF was tested in automatic mode. 8 drums with non active cemented products were produced there.

Fig. 4. Installation of the NPP at active water purification station of A1-NPP

CONCLUSION

Radioactive sludge stored in underground tanks has unsuitable mechanical physical properties to be treated in existing treatment facility at A-1 NPP. There are also problems with their transport or repeatable dosing.

The development and design of the MCF considered specific properties of sludge as well as condition and limits for the further treatment of cemented drums. The utilization of technology "in-situ" mixing minimizes transportation of sludge in long pipes or eliminates number of operations in the case when sludge is transported to the treatment facility in containers. Finally it minimizes number of operations with sludge and the amount of secondary radioactive waste. Technical equipment of the MCF allows operative control of amount of sludge's dry residue, which is fixed to matrix in drums. Thus the limits for loading of drums to container can be kept and container with waste can be deposited at National Repository.

The most of the operations are remote controlled and thus occupational dose of operators are minimized. Furthermore the radiation control system provides early signalization of equipment abnormal operation. Dosing system, which consists of two weighing units of powder matrix, and two weighing units of aqueous additives, allows to use the MCF not only to prepare cement matrix for fixation of radioactive waste, but also the other promising inorganic matrixes.

The functionality of the MCF was proved during extensive mock up tests. The MCF is able to perform all technological operations remotely in both, automatic and manual modes.

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