PROJECT
Preliminary studies for the decommissioning of the reactor compartments of the former Paldiski military nuclear site and for the establishment of a radioactive waste repository

Stage 3.
DETERMINING THE POSSIBILITIES OF DECOMMISSIONING THE REACTOR COMPARTMENTS

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Task 3 Determining the possibilities of decommissioning the Reactor Compartments

Scope of the work :

- assessment of potential options of the reactor compartments decommissioning taking into consideration international experience in the field of the dismantling of reactor compartments;
- development of a decommissioning concept for the reactor compartments;
- assessment of quantities and activity of waste to be generated in the course of the reactor compartments and sarcophagi dismantling following 50 years of storage depending on the decommissioning option;
- waste classification in compliance with the applicable documents of IAEA and the Estonian legislation;
- safety assessment of the reactor compartments decommissioning taking into account waste to be generated as a result of works.

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Subtask 3.1. Assessment of different methods used for decommissioning reactor compartments

Four options within two approaches for decommissioning have been considered.

Approach 1 (fragmentation)- Equipment dismantling and RC cutting.

- **Option A**: into big components in order to lower men exposure, to be followed with components packaging into shielded containers and final disposal in the newly built radwaste storage facility.
- **Option B**: into small components, to be followed with decontamination in order to minimize radwaste quantities that require final disposal.

Approach 2 (in situ)– Final disposal of the Reactor Compartments as a whole.

- **Option C**: - in situ, in the existing sarcophagi, following their reinforcement.
- **Option D**: - in a near surface RW disposal facility located near the main building on the former training center site.

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Subtask 3.1. Assessment of different methods used for decommissioning reactor compartments

Option A :

• the RCs are to be cut into big components;
• nuclear power installation equipment and big fragments are to be packed within shielding containers and transported for final disposal to the new-built facility;
• the option is characterized by moderate dose exposure.

Option B:

• the RCs and nuclear power installation equipment are to be cut into small components, that are to be decontaminated in order to have the majority of metal waste exempted from radiological constraints and, thus, minimize quantities of radwaste that requires final disposal;
• option is characterized by higher labor and dose exposure;
• requires considerable expenses for waste processing and purification of the gaseous environment;
• needs less shielded containers and much less space for radwaste disposal that leads to saving funds for the construction of a radwaste storage facility.

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Subtask 3.1. Implementation of the options A and B for RCs decommissioning

The implementation of the A and B options requires removal of the concrete poured within RCs prior to the long-term storage and removal of the solid RW placed within the concrete. Thus, the additional equipment are required:

1) instrumentation to “show through” the concrete to find inclusions (solid RW – metals, plastic, personal protective equipment, air filters etc.);
2) equipment/facility to crush and remove the concrete without any damage to the inclusions (p.1 above) and to the nuclear power installation components contacting the concrete.

RC 346A, placement of the concrete): reactor vessel lid at the fore apparatus partition-off– 4,7 m^3 ; within U-shape partition-off – 17,65 m^3 ; at the lid of the U-shape partition-off – 7,5 m^3 ; at the lid of the SG partition-off – 0,9 m^3.

Total volume of the concrete - 30,75 m^3.

RC 346B, placement of the concrete (m^3): at the shielding tank lid – 9 m^3 ; at the apparatus partition-off flooring– 31 m^3; at the lids of the pumps partition-off floorings of starboard and portside – 1,2 m^3.

Total volume of the concrete - 41,2 m^3.

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Subtask 3.1. Assessment of different methods used for decommissioning reactor compartments

Options C and D:

- additional volumes of RW are nor generated;
- minimization of labor and dose exposure;
- minimal environmental impact.

Differences between C and D:

- option C - RW disposal facility to be established through the reconstruction of the existing facilities of the MTB and the sarcophagi;
- option D - new RW disposal facility to be constructed near by the MTB.

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Subtask 3.3. Description and assessment of the waste to be generated in the course of the RCs decommissioning

Solid radioactive waste streams to be generated during the decommissioning of the 346 A and 346 B stands:

- waste whose activity is stipulated by the induced activity of the reactor structure components;
- waste whose activity is stipulated by corrosion and fission products on the surfaces of the primary circuit structure and equipment;
- waste from non-radioactive reactor structures and reactor shielding;
- waste placed for storage into the reactor compartments prior to the mothballing of the stands;
- waste resulting from the dismantling of concrete that had been poured into the reactor compartments prior to the mothballing of the stands;
- waste to be generated during the sarcophagi dismantling.

Radionuclides: ^{55}Fe; ^{60}Co; **^{59}Ni; ^{63}Ni; ^{94}Nb;** ^{152}Eu; ^{154}Eu

The main radionuclide that will determine the activity of the RCs radioactive waste after 50 years of storage is **^{63}Ni (from 80% to 99%);**

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Nomenclature of RW in the course of stand 346A RC dismantling

RW description	RW weight, kg	Specific activity, Bq/kg	RW classification	Radionuclides that determine that this is RW
VM-A reactor	**30 000**	**2,3 E+09**	**ML RW**	**Co-60, Ni-59, Ni-63 (97,8%)**
Shielding tank	**52 000**	**1, 6E+7**	**ML RW**	**Co-60, Ni-59, Ni-63**
Primary circuit equipment	**~38 000**	**Missing data**	**LL RW, VLL RW**	

Radioactive waste quantity is estimated at the time of the scheduled decommissioning, i.e. after 50 years of storage following the shutdown of the reactors. Classification has been made in accordance with the Estonian Radiation Act and the IAEA standards (№ GSG-1, 2014)

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Nomenclature of RW in the course of stand 346B RC dismantling

RW description	RW weight, kg	Specific activity, Bq/kg	RW classification	Radionuclides that determine that this is RW
VM-4 reactor (with internal components and control rods)	50 400	3,0E+08	ILRW	Co-60, Ni-59, Ni-63 Nb-94 Eu-152 Eu-154
Block steam generator – primary circuit pump	71 000	2,1E+04	LLRW	Co-60,
Primary circuit cooling system filter heat exchanger	2 780	2.8E+05	ILRW	Co-60, Ni-63
Primary circuit cooling system filter	1 980	3.9E+04	LLRW	Co-60
Shielding tank	66 180	4.6E+06	ILRW	Co-60, Ni-63, Nb-94

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Waste quantities during 346A and 346B power stands decommissioning for various decommissioning options

Waste description	Waste weight, kg	
	Stand 346 A	Stand 346 B
Options C and D. RC disposal as a whole		
RW of the categories ML RW, LL RW, VLL RW from RC	920 000	1 040 000
Waste resulting from the sarcophagus dismantling (non-radioactive)	650 000	610 000
RW total	920 000	1 040 000
Non-radioactive waste total	650 000	610 000

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RW quantities.
Option A Dismantling including cutting into big components

Waste description	Waste weight, kg	
	346 A	346 B
ILW radioactive waste from dismantling of primary circuit equipment	90 000	210 000
Waste from RC dismantling (cleared and non-radioactive)	765 000	740 000
Radioactive waste from cutting concrete with RW inside the compartments (category ILW for blocks of containers with ionizing radiation sources, LLW, VLLW for other concrete blocks)	65 000	90 000
Waste from sarcophagi disassembly (non-radioactive)	650 000	610 000
Total of RW	155 000	300 000
Total of non-radioactive waste	1 415 000	1 350 000

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RW quantities.
Option B Dismantling including cutting into small components

Waste description	Waste weight, kg	
	346 A	346 B
ILW radioactive waste from dismantling of primary circuit equipment	90000	210000
Waste from RC dismantling (cleared and non-radioactive)	765000	740000
Radioactive waste separated from concrete inside the compartments (category ILW for blocks of containers with ionizing radiation sources, LLW, VLLW for other concrete blocks)	15000	10000
Concrete (non-radiactive)	50000	80000
Waste from sarcophagi disassembly (non-radioactive)	650000	610000
Total of RW	105000	220000
Total of non-radioactive waste	1465000	1430000

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Summary for the RCs dismantling options assessment

- The final selection of options is recommended to be made following a technical and economical comparison of the options considered.
- Technical and economic parameters identified based on indicative assessments of the Options are given in the table below.
- Option B parameters have not been evaluated due to uncertainties with regard to the technology and equipment for decontamination and RW processing.
- Option B seems to be the preferred one from the strategic point of view.
- As can be seen from the data given below, Option C is the most economic one, but it is not fully compliant with IAEA recommendations for radwaste final disposal and is not acceptable for the developed West European countries, such as the UK, France etc.
- Additional technical and economical study is suggested following the selection of technologies for decontamination and RW processing. After this, the final RC decommissioning option for Paldiski can be selected.

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Basic parameters for the decommissioning of the former training center RCs

Option	RW weight (both of the RC), T	Labor, (thousands of man/hours)	Decom period (years)	Collective dose after 50 years of storage, (man- mSv)	Total cost, (M Eu)
Option C. Disposal in situ, in the existing sarcophagi	1960	117	3,5	110	8
Option D. Disposal as a whole in the new-built disposal facility	1960	214	5,5	190	12
Option A. Dismantling and cutting into big components	455	328	6,6	620	22
Option B. Dismantling and cutting into small components	325	369	7	720	25

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Possible end-points: Green and Brown field

Final condition of rehabilitated facility		Rehabilitation strategy	
«Brown field»	Territory of radiation hazardous facility	Facility renovation	Partial dismantlement and decontamination of constructions. Restoration of facility components properties. SNF and RW removal. Territory rehabilitation within SPA.
	(including facility for final disposal)	Facility conservation	Partial dismantlement and decontamination of constructions. SNF and RW removal and disposal of remaining materials with fixed contamination (secondary RW) on site. Territory rehabilitation within SPA.
		Facility conversion	Partial dismantlement and decontamination of constructions. SNF and RW removal. Territory rehabilitation within SPA.
	Territory of general purpose industrial facility	Facility liquidation	Full dismantlement of constructions. SNF and RW removal Territory rehabilitation within SPA.
« Green field»		Facility conversion	SNF and RW removal. Territory rehabilitation within SPA.
	Territory without special conditions of the use	Facility liquidation	Full dismantlement of constructions. SNF and RW removal. Territory rehabilitation within SPA.

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OPTION A - RC dismantling in large fragments (without cutting the reactor), followed by disposal

Description	Expert indicative conceptual evaluation						
	Terms (Days)	Cost (1000 Euro)	Manpower		Equipment		Doses Man-mSv
			qualification	Man-hour	equipment	Machine-hour	
preparations for the dismantling operations (organization of sanitary access mode, the installation of special ventilation, manufacturing of the protective cover, etc.).	180	2250	staff c. B	55 thousand.	Mobile sanitary point type SM-10M module for filtering 10M vacuum system to collect SRW	ignored	not expected
construction and equipping of "packaging shop"	150	3650	staff c. B	70 thousand.	construction equipment	ignored	not expected
RC and reactor dismantling equipment using a remote-controlled dismantling techniques	250	5700	staff c. A	40 thousand.	-Remote-controlled electro-hydraulic machine for dismantling Brokk 60 (100) with attachments; - Mobile sanitary inspection type SM-10M module for filtering 10M vacuum system to collect TPO	20 thousand.	300 mSv
Defragmentation reactor equipment in the "packaging shop" for large fragments, waste compacting	230	6200	staff c. A	50 thousand.	-Remote-controlled arm Craft grips; - Mobile sanitary inspection type SM-10M module for filtering 10M vacuum system to collect TPO	30 thousand.	200 mSv

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OPTION A - RC dismantling in large fragments (without cutting the reactor), followed by disposal

Description	Expert indicative conceptual evaluation						
	Terms (Days)	Cost (1000 Euro)	Manpower		Equipment		Doses Man-mSv
Decontamination of equipment and structures that are pollution PB loading (packing) of radioactive waste in the protective container	Thirty	1800	staff c. A	15 thousand.	-Equipment for decontamination	5 thousand .	100 mSv
transportation safety containers with radioactive waste disposal facility in	230	600	staff c. A	8 thousand.	special truck	5 thousand .	20 mSv
demolition of building structures and sarcophagi SCC object Paldiski	180	1800	staff c. B	90 thousand.	construction equipment	50 thousand .	not expected
In total	1250	22000		328thousand.		110 thousand .	620 Man-mSv

Concervative approach was used for assessment of the work-hours basing on the experts opinion. The otimization of workforce could be made on the basis of the design documentation and WBS

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OPTION B –RC dismantling into small pieces (without cutting the reactor), followed by disposal

Phase Description	Expert indicative conceptual evaluation						
	Terms (Days)	Cost (Thousand Euro)	Manpower		Mashinozatraty		Doses Man-mSv
			qualification	Man-hour	equipment	Machine-hour	
preparations for the dismantling operations (organization of sanitary access mode, the installation of special ventilation, manufacturing of the protective cover, etc.).	180	2250	staff c. B	55 thousand .	Mobile sanitary inspection type SM-10M module for filtering 10M vacuum system to collect TPO	ignored	not expected
construction and equipment "shop packaging"	150	3650	staff c. B	70 thousand .	construction equipment	ignored	not expected
RO and reactor dismantling equipment using a remote-controlled dismantling techniques	250	5700	staff c. A	40 thousand .	-Remote-controlled electro-hydraulic machine for dismantling Brokk 60 (100) with attachments; - Mobile sanitary inspection type SM-10M module for filtering 10M vacuum system to collect TPO	20 thousand .	300 mSv

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OPTION B –RC dismantling into small pieces (without cutting the reactor), followed by disposal

Phase Description	Expert indicative conceptual evaluation						
	Terms (Days)	Cost (Thousand Euro)	Manpower		Mashinozatraty		Doses Man-mSv
Defragmentation reactor equipment in the "packaging workshop" into small fragments, waste compacting	230	9000	staff c. A	80 thousand .	-Remote-controlled arm Craft grips; - Mobile sanitary inspection type SM-10M module for filtering 10M vacuum system to collect TPO	50 thousand .	300 mSv
Decontamination of equipment and structures that are pollution PB loading (packing) of radioactive waste in the protective container	45	1800	staff c. A	22 thousand .	-Equipment for decontamination	10 thousand .	100 mSv
transportation safety containers with radioactive waste disposal facility in	280	900	staff c. A	12 thousand .	special truck	8 thousand .	20 mSv
demolition of building structures and sarcophagi SCC object Paldiski	180	1800	staff c. B	90 thousand .	construction equipment	50 thousand .	not expected
In total	1315	25100		369 thousand		138 thousand .	720 Man-mSv

АТОМПРОЕКТ

INDICATIVE Work schedule and sequence of works

The following conditions:

- project target: green field;
- pressurized water reactor is located in concrete sarcophagi;
- 50 years decay time after reactor shut down approximately;
- waste treatment and packaging on site, external disposal;
-restrictions from licencing process.

Preparation stage
- ❑ Investigation, studies, Decisions, Concept …
- ❑ Modification of Estonia legal and regulation documents…
- ❑ Programs including funding …
- ❑ Survey, assessment of impact of environment, feasibility study, design documentation…
- ❑ Public hearing, licensing, permission…

Duration – 15-17 years

Main stage – works on Paldiski site
- ❑ Infrastructures…
- ❑ Dismantling…
- ❑ Decontamination…
- ❑ Waste handling…
- ❑ Remediation …

Duration – 20 years or more

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INDICATIVE ASSESSMENT OF THE QUANTATIVE AND COST PARAMETERS OF SRW MANAGEMENT FOR VARIOUS CONCEPTS

Concept A - RC dismantling in large fragments (without cutting the reactor), followed by final disposal

The indicative cost for processing of SRW - to about 24.16 mln. EURO (2015)

Concept B - RC dismantling in small fragments (without cutting the reactor), followed by final disposal

The indicative cost for processing of SRW - to about 21,25 mln. EURO (2015)

Container type	Application	Capacity	Quantity, pcs		Notes
			Concept A	Concept B	
Type A (steel shielding container)	Storage, transportation, disposal of RPV and internal components	30000 kg	1	1	New development
Type A (steel shielding container)	Storage, transportation, disposal of RPV and internal components	50000 kg	1	1	New development
Type IP-2 (steel shielding container)	Storage, transportation, disposal of Steam Generators	3000 kg	8	8	New development
Type IP-2 (steel shielding container)	Storage, transportation, disposal of Steam Generators	14500 kg	5	5	New development
Type IP-2 (steel shielding container)	Storage, transportation, disposal of SRW (large pieces)	33 m^3	42	-	New development
Type IP-2 (concrete container)	Storage, transportation, disposal of SRW	1 m^3	-	1300	Existing containers, or analogues
Type IP-2 (concrete container)	Storage, transportation, disposal of SRW	1.225 m^3	-	20	Existing containers, or analogues

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SUMMARY

The following was determined based on the surveys and analysis developed to determine if the reactor compartments of the former training centre in Paldiski can be decommissioned.

The analysis of various techniques used to decommission reactor compartments was carried out based on data published on the decommissioning of NPS dismantled in France, UK, USA, Germany and Russian Federation. Each of NPS possessing countries has its own dismantling concepts or strategies. The principal solution used in strategies of those countries are very similar in essence. The USA and the RF has the greatest experience in the dismantling because they dismantled a significant number of NPSs within the scope of Intergovernmental agreements on the threat reduction (more than 200 NPSs according to some sources). There are no published data on the dismantling of facilities similar to the former training centre in Paldiski. According to the concepts of the above countries from among the examples given, the NPS is to be dismantled one compartment after another, at that the reactor compartment shall not be dismantled or cut. A unit is to be made from one or two NPS reactor compartments. The unit is to be prepared for a long-term storage and then transported to the storage site. At present there are such long term storage sites to store reactor compartment units safely in all countries that own dismantled NPS. The period of such RC storage in the RF is assumed to be about 70 years. The research is in progress to find solutions on the future of RC being stored. None of counties that own dismantled NPS has started the RC dismantling for their final dismantlement and disposal of RW generated.

The similar concept on the accelerated decommissioning of stands 346A and 346B was implemented on the Paldiski site. The RCs were transferred into a safe state, some internal premises were concreted and after that the RCs were put in a concrete sarcophagus. There were no access into internals. The monitoring of radiation situation, temperature, air humidity was ensured inside the RC and inside the building comprising the sarcophagi. The task 2 report has confirmed that the RC sarcophagi are in a safe condition. The designed period of the sarcophagi storage is 50 years.

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SUMMARY

The following options of the decommissioning concept for the former training centre in Paldiski has been considered for the purpose of these preliminary surveys

- Concepts A and B with full dismantling and equipment dismounting: into large fragments to minimize dose exposure based on option A, into small fragments and using decontamination means to reduce the amount of RW generated based on option B. The reactors and reactor internals are not to be dismantled.
- Concept C – RC disposal as a whole unit without dismantling either in existing sarcophagi or in a newly constructed RW storage facility.

Concept C was excluded at the further stages of examination since it complies neither with existing requirements of European regulations nor with IAEA requirements.

Under Concept A the equipment and devices are required to be available to dismantle, crush the concrete, large-sized shielded casks are to be designed and manufactured to dispose large fragments generated.

Under Concept B the dismantling and concrete crushing equipment is also required but in this case decontamination and waste reprocessing means shall be widely used to reduce the amount of RW to be disposed.

The analysis of RC decommissioning options revealed that concept B is the most labor-intensive. It requires up-to-date equipment to be available:

To dismantle and cut reactor equipment;

To crush concrete without damaging the item located inside the concrete;

monitoring means allowing to 'see' foreign items inside the concrete;

units for various types of decontamination;

units to reprocess and condition RW generated.

The production infrastructure is also required to manufacture shielded casks (if existing certified casks could not be purchased) designed to load and store generated RW after its conditioning. It is required to ensure construction of an interim RW storage facility onsite to store casks loaded with RW before their transportation to the disposal facility newly built in the Republic of Estonia for the disposal.

On the other hand, concept B allows to reduce the amount of waste that requires final disposal and if implemented, the capacity of the RW storage facility would be the least due to the least number and size of the casks required to dispose the whole volume of RW generated and handling of other non-hazardous components.

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SUMMARY

The Concept of the RC Decommissioning in Paldiski was developed based on the analysis of selected RC decommissioning options taking into account IAEA requirements and indicative assessment of performance characteristics. The RC condition and expected amount of waste were taken into account during the Concept development. The Concept comprises the following sections:

- Definitions;
- Issue description and Concept objective;
- Concept application field;
- Normative legal base of the Concept;
- Main principles of the Concept;
- Technical and economic basis of the Concept;
- Principal solutions to implement RC decommissioning;
- Radiation safety and environmental protection;
- Conclusions.

It is assumed that the Concept proposed may be used as a basis for consideration and agreement by AS ALARA, the operator, as well as by the Ministers and bodies of the Republic of Estonia and subsequent approval by the Government of the Republic of Estonia.

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SUMMARY

The expert indicative assessment of concepts A and B (without cutting the reactor vessel) developed based on the following parameters:

- duration;
- cost;
- number of personnel and its qualification;
- usage of equipment, tools, and machinery;
- radiation exposure of Group A and B personnel;

for the principal stages of decommissioning activities revealed that the most efficient option for implementation is Concept B – cutting the building structures and equipment into small fragments.

Indicative total cost including SRW processing:

Concept A – 46, 160 mln EURO

Concept B - 46, 250 mln EURO

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SUMMARY

The safety analysis developed for Concept B based on respective criteria including assessment of risks during the works, including potential risks in case of off-optimum situations or incidents with the assessment of potential consequences, revealed that practical activities on RC decommissioning at Paldiski facility may be carried out sufficiently safely subject to meeting the main safety principals and up-to-date equipment usage.

The expert assessment of decommissioning activities was made during the analysis of chosen RC decommissioning option. More detailed safety analysis of RC decommissioning activities shall be developed based on completed CERS results and then at the stage of design documentation development.

When developing the safety analysis for the decommissioning the following was taken into account:

- the most part of radiation hazardous activities inside the RC may be carried out using remotely controlled equipment thus minimizing the personnel exposure.
- there is a number of process operations that shall be implemented with direct participation of qualified personnel. Those processes include:
  - all activities associated with the usage of oxygen acetylene cutting (including air plasma cutting), as well as welding;
  - decontamination;
  - process cleaning at working places;
  - on-line radiation monitoring at working places.

It shall be noted that the most hazardous are embedded spent neutron radiation sources inside the RC. Their position shall be determined as precisely as possible and they shall be removed and separated from the concrete as carefully as possible during the RC dismantling. The techniques and equipment for the process shall be developed at the design stage.

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