PURCHASE OF STUDIES FOR THE PREPARATION OF A DESIGNATED SPATIAL PLAN AND THE ASSESSMENT OF IMPACT

Activity 5. Comparison of reactor compartment decommissioning alternatives

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REVISION SHEET

Revisions of this document will be made by exchange of the complete document including the title page with signatures. Replacement of the individual pages is not permitted.

The revision is indicated in the header of all pages.

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Rev.	Reason for revision	Date of issue
01	Initial issue	13-11-2023
02	Evaluation of the Client’s comments	27-11-2023

CONTENT

ABBREVIATIONS

EU	European Union
FPNC	Former Paldiski Nuclear Center
IAEA	International Atomic Energy Agency
MTB	Main Technological Building
RC	Reactor Compartment
RW	Radioactive Waste

INTRODUCTION

This is the interim report intended to summarise the results of the studies performed in Activity 5, "Comparison of reactor compartment decommissioning alternatives. Activities related to the most suitable reactor compartment decommissioning alternative", including the Sub-activities 5.1 – 5.3 which were envisaged in the Technical Specifications of the Project "'Purchase of studies for the preparation of a designated spatial plan and the assessment of impact". The Sub-activities included the following studies:

Sub-activity 5.1: the study carried out to provide an analysis based on economic, radiation safety and other such aspects of the "zero alternative", i.e. preservation of mothballed RCs and storage of the packaged RW in the Interim Storage at the FPNC, and give an overview of the possible drawbacks and advantages entailed in the implementation of the "zero alternative" compared to the decommissioning of the RCs (see Appendix 1).

Sub-activity 5.2: the study carried out to present an initial analysis based on economic, radiation safety and other such aspects of the RC decommissioning alternatives and provide an overview of the possible drawbacks and advantages entailed in the implementation of different decommissioning alternatives (see Appendix 2).

Sub-activity 5.3: the preparation of a safety case and the RC decommissioning plan for the most suitable RC decommissioning alternative (see Appendix 3).

1. SUB-ACTIVITY 5.1. ZERO ALTERNATIVE

1.1 Review of "Zero Alternative" Options

"Zero alternative", i.e. preservation of mothballed RCs and storage of the packaged RW in the Interim Storage at the FPNC.

This concept is considered as an alternative to decommissioning RCs. The choice of the "zero alternative" is made from the following possible options:

- Option 1: prolonging safe enclosure of the reactors for additional time period and postponing decommissioning works;
- Option 2: leaving the reactors not dismantled for ever, i.e. prolonged storage waiting until clearance levels are reached;
- Option 3: on site disposal (entombment).

1.2 Option 1. Prolonging Safe Enclosure of the Reactors for Additional Time Period and Postponing Decommissioning Works

According to the international experience, the main reason for deferred dismantling is the decay of short-lived nuclides. It is well known that the main (or even the only one) advantage of the "safe enclosure" options is reduction of radioactivity. Decay of short-lived radionuclides results in:

- significant reduction of doses during dismantling;
- reduction of amount of the waste, as well as reduction of the disposal facility size;
- simplification of dismantling process (no needs for robots or remotely managed tools as the dose rate is insignificant);
- simplification of waste management process.

The main question is to what extent it is expedient to extend the exposure time of the RCs. At the same time, it is understood that the extension of the holding time of the RCs in no way affects a significant decrease in the activity of spent sealed sources. The main dose-forming nuclide for external exposure of personnel is Co-60. With a total activity of Co-60 in the RC 346A 1.93 E+11 Bq (2039 year), the dose of external exposure of personnel during the dismantling work will decrease by more than 4000 times over 60 years, which will make it possible to perform most of the work without the use of remotely controlled equipment. Therefore, the holding period for RCs for option 1 is considered until 2100.

Throughout the entire period of operation (during the "zero alternative" period until 2100 year plus 10 years for dismantling works), the MTB will perform the specified functions and maintain the necessary performance characteristics. The main requirement that determines the reliability of the construction of a facility is its suitability for its intended purpose and the ability to maintain the necessary operational qualities during the established period of operation. These include:

- guarantee the safety of human health and life of people, property and the environment;

- maintain the integrity of the facility and its main parts and fulfil other requirements that guarantee the possibility of using the facility for its intended purpose and the normal functioning of the technological process, including meeting the requirements for the reliability of building structures and foundations, their heat and sound insulation properties and tightness;
- ensure the possible development of the facility and its adaptation to changing technical, economic or social conditions;
- create the necessary level of convenience and comfort for users and operating personnel, including the requirements for maintaining the climatic regime in the premises (air exchange, temperature, humidity, illumination level, etc.), as well as accessibility for inspections and repairs, the possibility of replacing and upgrading individual elements;
- limit the level of risk by fulfilling the requirements for fire protection, non-failure operation of protective devices, reliability of life support systems and networks, survivability of building structures.
- The building structures of the MTB, the structures of sarcophagi and the Interim Storage act as barriers to the possible spread of radioactive substances and ensure the safe operation of the building as a whole.
- Based on the experience of assessing the durability of building structures of such construction, the recommended value of the time from the moment of construction of structures to the moment of exhaustion of its resource for industrial buildings made in reinforced concrete structures is estimated at about 100 years.
- The construction of the MTB was carried out in the early 1960s. At the time of the 2022 survey, the age of the structures was estimated at about 60 years.
- Taking into account the work on the complete reconstruction of the MTB that was completed in the early 2000s and the possibility of extending the design life of the facility, it is conservatively assumed that the life of the MTB under "zero alternative" will expire by 2100 (100 years from complete reconstruction date).
- The prospect of extending the design life beyond 100 years should be considered on the basis of a comprehensive survey and assessment of the residual resource of building structures and the building as a whole at the end of the building's design life.

1.3 Option 2. Leaving the Reactors as They are for Ever, i.e. Prolonged Storage Waiting until Clearance Levels are Reached

Option 2 proposes maintaining the *status quo* for the time necessary to reduce the activity of radionuclides to levels of withdrawal from regulatory control.

In order to estimate the time required to achieve the levels of release from regulatory control, the main RW accumulated on the site are considered below:

- equipment in RCs;

- spent sealed sources, which were placed in the RC No. 1 during the conservation works;
- RW placed in the Interim Storage.

Almost all (99%) amount of activity of radionuclides in the equipment of RCs is determined by the radioactivity of the reactors and reactor internals. Since the mass characteristics of the equipment are known, and the equipment itself is considered as a whole, the exemption and clearance levels for radioactive substances established by the Estonian regulation can be taken as a criteria for the release of equipment from regulatory control.

As follows from the results of activity data analysis, the main RW accumulated at the Paldiski site cannot be released from regulatory control in the foreseeable future (tens of thousands of years that are required to achieve the release criteria), which excludes this option from the scope of the review.

1.4 Option 3. On Site Disposal (Entombment)

Option 3 proposes the conversion of the existing building with RCs into a facility for RW disposal. The MTB, which houses the storage facility of RW and RCs, is a surface structure. RW in the Interim Storage, equipment and materials inside RCs, and spent sealed sources contain long-lived radionuclides.

According to the IAEA classification of RW (GSG-1): «Intermediate level waste (ILW): Waste that, because of its content, particularly of long-lived radionuclides, requires a greater degree of containment and isolation than that provided by near-surface disposal. However, ILW needs no provision, or only limited provision, for heat dissipation during its storage and disposal. ILW may contain long-lived radionuclides, in particular, alpha-emitting radionuclides that will not decay to a level of activity concentration acceptable for near-surface disposal during the time for which institutional controls can be relied upon. Therefore, waste in this class requires disposal at greater depths, of the order of tens of metres to a few hundred metres».

Because disposal of long-lived waste in near-surface disposal facilities is considered unsafe, this option is excluded from consideration.

1.5 Analysis of Factors Influencing the Choice of an Option 1 “Prolonging Safe Enclosure of the Reactors for Additional Time Period and Postponing Decommissioning Works”

1.5.1 Evaluation of economic factors

When assessing the financial costs for this option, it was assumed that no measures would be taken to create an infrastructure for RW management (a conditioning workshop and the creation of a RW disposal facility) and the refusal to carry out work to dismantle equipment and building structures after 2040. That is, this scenario assumes non-intervention in the situation and the continuation of the operation of the MTB in its current state. It can be said that from a financial point of view, for the entire period of keeping stands 346A and 346B in a state of conservation, this scenario may look more attractive than the base one (an option that involves the dismantling of equipment and building structures and then management of the resulting waste). Since for the period at least until 2100, there will be a need to provide only operating costs for maintaining the building and supporting systems in working condition. These costs are comparable to the cost of operating the main technology building in any other scenario that assumes a holding period until 2040.

However, given that both building structures and technological systems cannot ensure the safe long-term storage of RW (until the conditions for release from regulatory control are met), it will be necessary to dismantle RCs and MTB, eventually set up facilities for the management of accumulated RW and waste disposal in accordance with established norms.

The economic factors for the implementation of the "zero alternative” include the following components:

- operating costs between 2040 and 2110 (during the "zero alternative" period until 2100 year plus 10 years for dismantling works);
- refurbishment of the MTB for safe storage of the RCs and RW.

The operating costs for the maintenance of the MTB and engineering systems over a period of 60 years are estimated amount will be up to 39 million euros (taking into account the current annual budget about 650,000 euros). The costs include engineering surveys, regular repairs, replacements engineering systems, labour costs.

Additionally, 75 million euros will be needed for major repairs and refurbishment of the MTB for safe storage of the RCs and RW.

Expenses for the dismantling of the RCs, the MTB, and the removal of containers from the storage facility for disposal, the creation of infrastructure for the management of radioactive and non-radioactive waste should be assessed in the decommissioning project of the main process building. For work carried out after 2100, inflation will be the determining factor.

This cost does not take into account the costs of RW disposal, which are generated during the dismantling process. With an expected amount of RW of 350 tons (100–150 m^3) generated during dismantling in 2040 and subject to disposal, the cost of disposal will be from 3.12 million euros. When implementing the zero option, the amount of waste to be disposed of may decrease by 2100 by no more than 20%, because RC equipment (reactor vessels with internals, shielding tanks, etc.) that has been subjected to neutron irradiation contains long-lived nuclides that are subject to disposal in geological formations.

1.5.2 Assessment of radiation factors

It is supposed that the radiation criteria for releases and discharges specified in Regulation No. 40 “Conditions for Exclusion and Release of Radioactive Substances Used or Generated in Radiation Operations and Requirements for Requests for Exclusion and Release” for additional time period will be met by applying a special work technology, maintaining safety barriers and controlled for compliance by a radiation monitoring system. Under normal operation conditions, radiation exposure of the population and the environment is not expected. But if the “prolonged zero alternative” is implemented, the waste inside the building will not be completely immobilised for a long time. It can cause environmental pollution and exceed the permissible levels of public exposure as a result of the failure of existing engineering barriers.

During normal operation, the most dangerous work, from the perspective of personnel exposure, will be dismantling of equipment of RCs and management the resulting RW. Not exceeding the annual dose limit will be ensured by exposure planning, an exposure time limitation and the use of additional shieldings as well as dose rate control at workplaces and individual dosimetric control of personnel. Taking into account the significant decrease in the activity of Co-60 by 2100, if the “prolonged zero alternative” is implemented, it’s estimated the collective dose will not exceed 140 man-μSv. This will mainly occur due to the need to extract various types of RW stored in storage facilities, radiation sources from building structures, during the dismantling of reactor vessels.

It should be noted a lot of safety-related uncertainties due to our relatively limited knowledge about RCs. For example, over a long period of long-term storage, possible corrosion processes inside the RC can lead to the risk of leakage of radioactive substances into the environment. Elimination of the consequences of such an accident will lead to additional radiation exposure of personnel.

1.5.3 Assessment of non-radioactive factors

It can be noted that there is no negative impact of non-radiation factors on the environment, since the implementation of the "prolongation zero alternative" concept does not assume any additional activities associated with the generation of non-radioactive waste.

Under "prolonged zero alternative" the structures will be maintained in working condition, without any dismantling work for the entire period until 2100 and without any additional emissions and discharges during the normal operation.

1.5.4 Regulatory compliance

When considering the “prolonged zero alternative” option, various options for the decommissioning of nuclear installations laid down in the IAEA safety guides should be taken into consideration. In accordance to IAEA recommendations, disposal, during which the entire nuclear installation or part of it is encased in structurally robust materials, is not considered as a decommissioning strategy and is not an acceptable option in the event of a planned shutdown. It can only be considered as a possible solution in exceptional circumstances (e.g. after a severe accident).

The analysis of RW in the RCs and the Interim Storage shows that according to the classification currently used in Estonia, they hold a significant amount of low – and intermediate level long-lived RW. In accordance with the IAEA recommendations (GSG-1), medium-level waste containing large amounts of long-lived radionuclides is unacceptable for near-surface disposal and requires disposal at a depth of tens to several hundred meters. Consequently, without the dismantling of structures, removal and appropriate conditioning of all RW that do not meet the near-surface disposal requirements, such decommissioning option cannot be accepted.

The implementation of the zero option with prolonging safe enclosure of the reactors assumes that for a long time (more than 60 years) there is a radiation hazardous object on the territory of the FPNC. Safety barriers must be maintained at the facility in a safe condition.

Modern experience shows that the international situation in the world has changed dramatically over the past 20 years. The nuclear facilities can become targets of a terrorist act or military attacks of other countries. The risk of an impact on the environment, personnel and the public will be significantly higher than the option of completely dismantling the building and its contents within a shorter period.

Also it should be borne in mind that without solving the issue of safe waste disposal or postponing such a decision for a long time the “prolonged zero alternative” scenario directly contradicts the IAEA recommendations and the obligations assumed by Estonia under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management in part of not shifting the burden to future generations.

1.6 Executive Summary

Several options for the “zero alternative” were analysed:

- Option 1: prolonging safe enclosure of the reactors and postponing decommissioning works up to 2100;
- Option 2: leaving the reactors not dismantled forever, i.e. prolonged storage waiting until clearance levels are reached;
- Option 3: on site disposal (entombment).

Options 2 and 3 were excluded from further consideration due to a number of reasons (impossibility to meet safety requirements, non-compliance with international standards, etc.). According to the results of the preliminary analysis, the scenario of “Prolonging safe enclosure of the reactors for additional time period and postponing decommissioning works“ was chosen for a detailed review.

A selected option should be considered based on such factors as the economic component, reducing the risk to personnel and the environment during decommissioning work, compliance with the regulatory requirements.

The main advantages and disadvantages of the "zero alternative" concept are reviewed in Table 1.1.

Table 1.1 Analysis of the "zero alternative" scenario

Considered factor	Advantages	Disadvantages
Economic factor	Maintaining the facilities in working condition and monitoring the RW until 2100 will incur only operating and refurbishing costs. The costs of performing complex dismantling works and building a RW management facility can be attributed to the period after 2100.	Maintenance works will be required if the scenario with a long-term delay of work associated with the dismantling of RCs and subsequent RW management and disposal (for 60 years starting from 2039) is considered. In this case, postponing solutions for the long term will result in a significant increase of the work cost due to an increase of the money value over time (inflation, market price growth, etc.).
Radiation and non-radiation factors	Personnel exposure doses under this decommissioning option will be very insignificant, due to decay and smaller amount of RW to be transported and disposed.	RW located in the MTB contain intermediate level long-lived radionuclides, the activity of which will not decrease to the clearance levels in the foreseeable future. It means that the criteria for unrestricted use of the territory of the Paldiski site are not met. RW in the Interim Storage collected in concrete and steel containers in both conditioned and unconditioned state must be regularly inspected and reconditioned if needed. Considering limited knowledge about the condition inside RCs there is a possibility for radioactive releases from the RC due to corrosion. There are lots of safety-related uncertainties.
Compliance with the regulatory requirements	-	Without solving the issue of safe waste disposal or postponing such a decision to a distant future violates the EU policy and obligations of Estonia under the Joint Convention.
Additional risk	-	The nuclear facilities can become targets of a terrorist act or military attacks of other countries. The risk of impact on the environment, personnel and the public will be significantly higher if prolonging safe

Considered factor	Advantages	Disadvantages
		enclosure of the reactors for additional time period and postponing decommissioning works is taken.

The review of the “zero alternative” concept showed that the option “Prolonging safe enclosure of the reactors for additional time period and postponing decommissioning works “ as well as other options have many disadvantages: additional costs for the operation of the MTB and an increase in the cost of implementing the RC dismantling over time, the difficulties in ensuring engineering barriers long-term safety and an additional risk due to the danger of external aggression. Also, the implementation of the "zero alternative" does not comply with the EU policy and the IAEA recommendations for nuclear facility’s decommissioning options in part of not shifting the burden to future generations. Reduction of personnel doses during decommissioning and some reduction in the RW amount requiring disposal does not have a significant impact on the consideration of the “zero alternative”.

Given the many disadvantages, this decommissioning option should not be considered as an acceptable choice.

2. SUB-ACTIVITY 5.2. INITIAL COMPARISON OF ALTERNATIVES

2.1 Decommissioning Options

The comparison of two decommissioning options for the reactor facilities of the FPNC in order to achieve the final state have been done. These options are as follows:

- Option A: the dismantling of the RCs, including reactor equipment and structures; cutting the resulting components into small fragments. In this case, it is assumed that the reactor vessel will be fragmented into small parts and shipped/transported for disposal in standard containers;
- Option B: the dismantling of the RCs, including reactor equipment and structures; cutting the resulting components into small fragments. In this case, the reactor vessels will not be fragmented but sent intact for disposal in special containers.

2.2 Description of Decommissioning Options

2.2.1 Option A – Dismantling and fragmentation of reactor vessels

In accordance with option A, the decommissioning of the FPNC reactor installations will be carried out in several stages, including final shutdown; conservation; holding period and dismantling.

To date, the "final shutdown" and "conservation" work has been completed at the FPNC. RCs are in long-term storage (the stage of “holding period").

During the holding period, the residual activity of the most radioactive equipment will be significantly reduced, which will allow the complete dismantling of the RCs without the risk of significant exposure of the personnel and without the need for expensive robots.

By the beginning of the "dismantling" stage, a RW treatment center must be established. By that time, the repositories for disposal of containers with conditioned RW that have been generated during the dismantling of RCs and temporarily stored in the MTB should be built. Installations for RW decontamination, conditioning and packaging should be installed.

At the "dismantling" stage, the site must be cleaned from existing buildings and structures and the site will be brought to "greenfield site" condition. During dismantling, the following will be performed:

- the existing RW packages that are currently stored in the MTB will be extracted and sent for disposal;
- the contaminated and uncontaminated equipment and structures, including the RCs, as well as auxiliary equipment located in existing buildings will be dismantled;
- RW will be managed and sent for disposal;
- non-radioactive waste will be managed and sent for reuse or disposal;
- the existing buildings and structures: MTB, ventilation chimney, entrance, water storage tank, biological wastewater treatment plant, engineering networks and site fencing will be demolished;

- reclamation of the territory will be carried out.

Performance of dismantling works assumes initial dismantling of the RCs followed by cutting structures and equipment into small fragments (with fragmentation of reactor vessels) so that the final volume of waste is minimised and standard containers can be used. Subject to the results of radiation measurement, the waste from RCs will be sorted out and separated into radioactive and non-radioactive waste.

RW will be sent to RW management facilities for subsequent decontamination, fragmentation and packaging. RW will be segregated into Low-Level waste and Intermediate-Level waste taking into account the established Waste Acceptance Criteria for near-surface disposal. Mixing of the different level wastes should be avoided. After characterisation, the conditioned (packaged) RW will be sent for disposal. Non-radioactive waste, after being released from regulatory control, will be sent for processing and reuse or disposal as industrial waste.

2.2.2 Option B – Dismantling without fragmentation of reactor vessels

Under option B, the RCs at the FPNC will be dismantled in the same consequential sequence as under option A. The work that needs to be done before the start of the “dismantling” phase, as well as the work performed during the dismantling, will be also similar to option A.

The dismantling of the RC No. 1 and RC No. 2 will start with the cutting of structures and equipment into small fragments (without fragmentation of the reactor vessels) in order to minimise the final volume of waste sent for disposal.

Opposite to option A, option B provides that, after removing the protective tank from the caisson, the reactor vessel will be loaded as one structure into a special shipping/disposal container.

Option B solutions for technological systems, water supply and sewage systems, ventilation, power supply, etc. are similar to option A.

2.3 Comparison of Dismantling Options

2.3.1 Main Technical and Economic Indicators by Options

The main technical and economic indicators for comparison by options are presented in Table 2.1.

Table 2.1 Technical and economic indicators of options

Indicators	Option A	Option B
The duration of the "dismantling" stage, years	8	7
Expected dose during dismantling of RCs	identical	
Expected dose due to fragmentation of reactor vessels, man-µSv	197,402.5	-
Expected dose of dismantling of the MTB and infrastructure for RW management	identical	
Committed dose from the dismantling of the remaining buildings on the site, external networks, roads and fences	identical	
Labor costs, person-month	995.97	919.76

Indicators	Option A	Option B
Waste from the dismantling of RCs, incl:		
- non-radioactive waste, kg	2,870,000	
- RW, kg	300,000	
- hazardous non-radioactive waste, kg	1992	
The cost of dismantling RCs, thousand euros	25,544.0	24,138.8
The cost of containers for the removal of conditioned RW and reactor vessels, thousand euros	1,355.0	3,457.5

RW management for options A and B is identical, except for the need to fragment the reactor pressure vessels, and dose exposure to personnel for the options will differ only in terms of taking into account the work on fragmentation of the reactor pressure vessels.

When fragmenting reactor vessels, an increase in the total collective dose of personnel received during the dismantling of equipment and building structures of the RC is expected to increase by approximately 35%.

2.3.2 Analysis methodology

A formalised decision-making technique known as multi-attribute utility theory (MAUT) was used to compare both considered options. This methodology allows comparison of proposed decommissioning options both in terms of quantitative and qualitative parameters available at the time of the analysis.

In this document the methodology used to compare the proposed options is recommended by IAEA (NP-T-1.10). This methodology is normally used to identify the strategy of and develop programs for the development of the nuclear energy industry, including, the cases where it is required to justify behaviour choices (in this case, decommissioning) of nuclear fuel cycle facilities.

In order to select the optimal option, groups of criteria (indicators) were identified at the MAUT analysis that characterises the “key elements” of the comparison between the options. In accordance with the selected methodology, the comparison is across the following groups of criteria that can characterise the actual decommissioning of a nuclear facility at the FPNC:

- Site considerations - K1;
- Safety - K2;
- Technical and other characteristics - K3;
- Radiation protection - K4;
- Environmental impact - K5;
- Site security - K6;
- Owner’s scope of supply - K7;
- Supplier issues - K8;
- Project schedule capability - K9;
- Economics - K10.

For each option the following is considered:

- The weight indicator of the fulfilment applied to the total value for each group of criteria (indicators), i.e., for the "key elements";
- The total weight indicator that is a sum of criteria applied across the entire set of indicators;
- Priority is given to the option with the highest summation score.

Each indicator is then compared to others in the table, with an explanation of the position of the experts. According to the results of the MAUT analysis, the best options for the decommissioning plan for the nuclear facility is recommended.

2.3.3 Summarized results of the decommissioning options analysis

According to the results of MAUT analysis, the option without fragmentation of the reactor vessel scored the maximum number of points. The summarised results of the analysis for individual groups of the main criteria are given in Table 2.3.

Table 2.2 The results of the comparative analysis according to the main criteria

Criteria number	Criteria	Option A Fragmentation	Option B The reactor vessel is not fragmented
K1	SITE SPECIFIC CONSIDERATIONS	0.2025	0.2175
K2	SAFETY	1.0375	1.0725
K3	TECHNICAL AND OTHER CHARACTERISTICS	0.6405	0.6405
K4	RADIATION PROTECTION	0.465	0.475
K5	ENVIRONMENTAL IMPACT	0.5	0.5
K6	SITE SECURITY	0.1	0.1
K7	OWNER’S SCOPE OF SUPPLY	0.1	0.1
K8	SUPPLIER ISSUES	0.094	0.094
K9	PROJECT SCHEDULE CAPABILITY	0.288	0.279
K10	ECONOMICS	0.742	0.886
TOTAL		**4.17**	**4.36**

Analysis of the individual groups of criteria shows that:

- **Option A "Dismantling and fragmentation of reactor vessels"** is the best option in terms of Project schedule capability. However, this option has average values or inferior to option B for all other comparison criteria.
- **Option B "Dismantling without fragmentation of reactor vessels"** is preferable to other options if the groups of criteria such as "Site features", "Safety", "Radiation

protection" and “Economics” are considered; this advantage can be attributed to a relatively smaller number of traffic flows and a lower dose load on personnel and labour costs than in option A. Also, this option scored relatively low on the Project schedule capability criteria, since the implementation of this option depends on development and licensing of large-size waste containers. This option received the highest score.

Thus, according to the results of the integrated assessment of all groups of criteria for all the options, the option B "Dismantling without fragmentation of reactor vessels" is the preferred option.

2.4 Executive Summary

Two decommissioning options for the FPNC RC’s were considered:

- Under Option A **"Dismantling and fragmentation of reactor vessels"** RCs, including reactor equipment and structures will be dismantled and the resulting components cut into small fragments. The reactor vessel will be fragmented into small parts and disposed of in standard containers.
- Under Option B **"Dismantling without fragmentation of reactor vessels"** RCs, including reactor equipment and structures will be dismantled and the resulting components cut into small fragments. The reactor vessels will not be fragmented but transferred as a whole for disposal in special containers.

When comparing options, a formalised decision-making technique known as multi-attribute utility theory was used.

According to the analysis, option B providing for dismantling of the reactor vessel without fragmentation scored more points across all groups of indicators except for K9 “Project Schedule Capability”.

Both concepts require the procurement of equipment for the demolition of building structures and concrete crushing; special facilities for decontamination, fragmentation and compaction of RW. However, the Option B (without reactor vessel fragmentation) provides for lesser personnel doses compared to Option A, and it is thought to result in a lesser amount of waste that will be sent to disposal.

3. SUB-ACTIVITY 5.3. PREPARING A SAFETY CASE

3.1 Reactor Compartment Decommissioning Plan

3.1.1 Content of the reactor compartment decommissioning plan

The content of the document "Decommissioning plan" was developed based on the IAEA recommendations (SRS-45). Below is a list of the main topics contained in the decommissioning plan:

- Facility description
- Decommissioning strategy
- Project management
- Decommissioning activities
- Surveillance and maintenance
- Waste management
- Cost estimate and funding mechanisms
- Safety assessment
- Environmental assessment
- Health and safety
- Quality assurance
- Emergency planning
- Physical security and safeguards
- Final radiation survey

Much of the information required for a decommissioning plan already exists as complete documents in itself, including the decommissioning safety assessment, radiation protection program, cost estimate, waste management program, quality assurance program, emergency plan, etc. The decommissioning plan incorporates these documents by reference with a summary provided in the plan.

3.1.2 Facility description

The FPNC decommissioning plan gives site location, building and system description. The data is presented on the basis of materials from completed engineering studies (Sub-activity 4.1, Sub-activity 4.2 and Sub-activity 4.5) and documents developed during the analysis of the state of the FPNC.

Information is also provided about the object's radiation status. It is presented in an abbreviated form based on survey reports (Sub-activity 4.3 and Sub-activity 4.4) and safety assessment developed and presented in the Sub-activity 4.8 report.

In addition, a short operational history of the facility including any significant events, which might have an impact on decommissioning, authorisation and licence history, previous decommissioning activities are provided.

3.1.3 Decommissioning strategy

Various alternative options for decommissioning the reactor facilities at the FPNC and a reasonable choice of the most appropriate option have been considered. Preliminary studies carried out in 2014–2015 provided information on possible decommissioning options.

The considered approaches to decommissioning strategies options describe the process of choosing the most appropriate option based on reports of Sub-activity 5.1 and Sub-activity 5.2 are identified.

The process of decommissioning facilities in accordance with the adopted strategy is divided into the following stages:

- Final closure;
- Conservation;
- Holding period;
- Dismantling.

At the "dismantling" stage, the site must be cleaned from existing buildings and structures and the site will be brought to "greenfield" condition. During dismantling, the following will be performed:

- the existing RW packages that are currently stored in the MTB will be extracted and sent for disposal;
- the contaminated and uncontaminated equipment and structures, including RCs, as well as auxiliary equipment located in existing buildings will be dismantled. The dismantling of RCs will be carried out by cutting of structures and equipment into small fragments (without fragmentation of the reactor vessels) in order to minimise the final volume of waste sent for disposal;
- RW will be conditioned, sorted, characterised and sent for disposal;
- non-radioactive waste will be managed and sent for reuse or disposal;
- the existing buildings and structures: MTB, ventilation stack, gate building, water storage tank, biological treatment plant, engineering networks and site fencing will be demolished;
- reclamation of the territory will be carried out.

3.1.4 Project management

A description of the regulatory framework in force in Estonia, system of licensing, inspection and enforcement is given. Brief information on approaches to organising a decommissioning project, organisations involved in project management and their responsibilities is presented.

3.1.5 Decommissioning activities

A summary of the decommissioning tasks planned for systems, equipment, or major components, in the order in which they will be performed, a summary of the remediation tasks planned for surface and subsurface soil at the site is provided in detail.

Based on previously completed work on preliminary studies for the decommissioning of the RCs of the FPNC and for the establishment of a RW repository (reports of Activity 3, Sub-activity 4.8 and Activity 5) a preliminary schedule for decommissioning work is provided. The implementation schedule for the decommissioning of the RCs of the FPNC is shown in Figure 3.1.

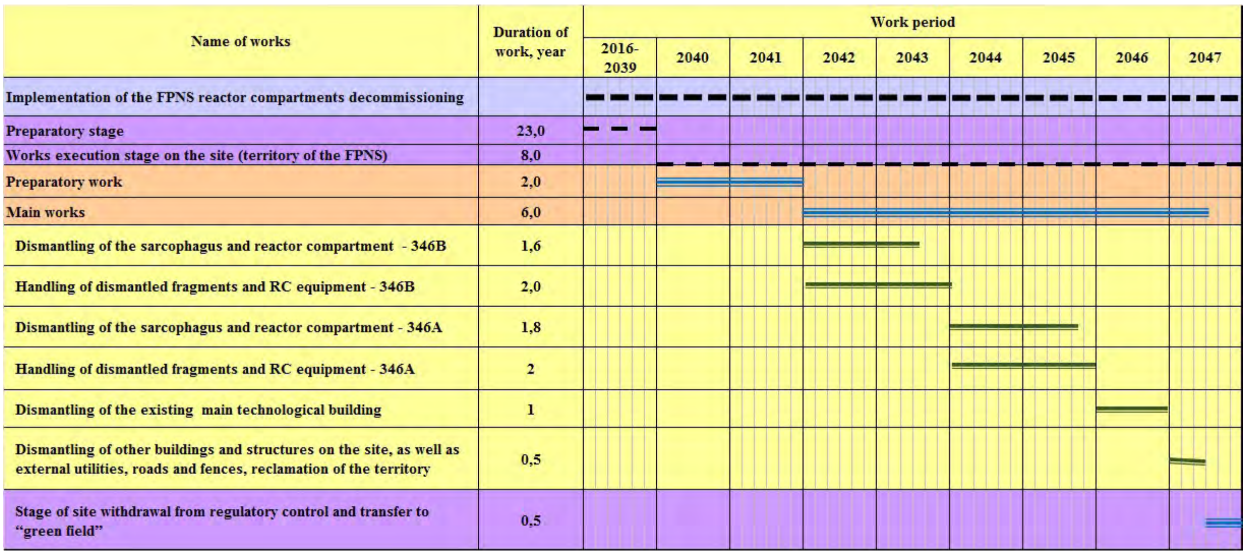

Figure 3.1 RCs decommissioning implementation schedule

3.1.6 Surveillance and maintenance

During the decommissioning of reactors in the MTB, existing systems can be used if their technical condition and technical characteristics by the time the reactor decommissioning works begin meet the functional requirements imposed on them, otherwise the elements of the systems must be replaced.

At the stage of dismantling, systems will be monitored in accordance with the operational guides for these systems. Maintenance of systems, including technical inspection and current repairs will be carried out by operating personnel or repair services and the records of the technical condition and inspection will be entered in the maintenance log. General approaches to organising surveillance and maintenance of systems and equipment is provided.

3.1.7 Waste management

All the possible waste streams that might be generated as a result of the decommissioning activities are identified. A summary of the types of RW that are expected to be generated during the decommissioning activities is provided based on reports of Sub-activity 4.3 and Sub-activity 4.4, including concrete, contaminated piping and structural material such as steel, activated components. The types of waste streams are specified according to the hazard posed and the waste classification system adopted and include RW, hazardous waste, and other types.

An estimate is provided of the volumes and weights of each type of solid waste according to the waste stream, the amount of radioactivity by radionuclide.

A description of the procedures for treating, conditioning, packaging and storing each type of solid waste on-site prior to shipment for disposal is also provided based on the results presented in the Sub-activity 4.8 report.

3.1.8 Cost estimate and funding mechanisms

Cost estimate is presented based on assessment for RW National Development Plan and a description of the current state for funding mechanisms of decommissioning activities is given.

Decommissioning will be financed of resources of the state budget. Thus the financial capacity to maintain and, if necessary, improve the safety of facilities for RW management in accordance to the regulatory requirements is ensured.

3.1.9 Safety assessment

This section provides a brief description of the results presented in the reports on safety assessment (Sub-activity 4.8) and risk analysis (Sub-activity 4.10).

3.1.10 Environmental assessment

A description of the possible impact on the environment of the planned activity (dismantling work) carried out on the basis of the proposed engineering solutions, the environmental components that may be affected by the planned activity and the environmental monitoring program is given.

3.1.11 Health and safety

Health and safety issues are governed by two programs: the radiation protection program and the industrial health and safety program. The programs in place during the operating period form the basis for the continuing programs required throughout the decommissioning period.

A preliminary plan for radiation protection at the stage of dismantling the RCs was developed as part of Sub-activity 4.9. The section presents the main provisions of the program based on this report.

3.1.12 Quality management

The basic requirements for developing a quality management system are provided. Principal obligation of holders of radiation practice licences includes being responsible for radiation safety and guarantee the physical protection of the radioactive sources in the holder's possession, also developing and implementing a radiation safety quality system. Radiation safety quality management system must cover

- planned and systematic activities whose objective is to ensure radiation safety;
- analysis of duties, and skills required for and requirements for use of radiation sources which include, in particular, description of radiation practice, guidelines for radiation practice, workers' training procedure;

- requirements for procurement, use and disuse of materials and equipment;
- description of radiation safety procedures implemented during radiation practices;
- procedure for controlling the functioning and improvement of the radiation safety quality management system.

3.1.13 Emergency planning

During the design stage of the FPNC decommissioning, an emergency management system should be developed. The main approaches to developing an emergency response plan are provided.

3.1.14 Physical security and safeguards

The Paldiski site has a functioning physical protection system. To implement the plan for the dismantling of RCs and MTB, no changes to the existing system are expected, because the MTB is located inside the guarded perimeter of the FPNC.

3.1.15 Final radiation survey

A brief overview of the data collection procedure and comprehensive engineering and radiation survey is provided.

3.1.16 Final decommissioning plan

This initial decommissioning plan should be subsequently updated to reflect information on changes of equipment or processes, unplanned events, changes in support capabilities including waste management and radiological monitoring, update of radiological conditions, changes in legislative requirements, changes in financial assumptions and improvements in decommissioning technology, etc.

The decommissioning plan should be finalised approximately three to five years before the safe enclosure phase ends. This final plan will be detailed and will approve by the regulatory body before implementation of the final decommissioning strategy, i.e. decontamination and dismantling. This plan is the basis for the development of the detailed work instructions and procedures.

3.2 Safety Case

3.2.1 Content of safety case

The safety case was performed in accordance with the recommendations of IAEA. The safety case includes a description of how all the safety aspects of decommissioning of the facility, and the managerial controls satisfy the regulatory requirements. The safety case and its supporting safety assessment demonstrate the level of protection provided and give assurance to the regulatory body that safety requirements will be met.

Below is a list of the main topics contained in the safety case:

- Context for the safety case;
- Strategy for safety;
- Safety assessment;

- Synthesis and conclusions.

Each of these topics is discussed in detail. The document is a summary document based on the results of previous activities related to safety assessment, risk analysis and estimation of the transboundary impacts.

3.2.2 Context for the safety case

A brief description of the history of the FPNC, building structures and reactor facilities is provided. A description of the planned activities for the RCs decommissioning is also provided.

In addition, relation to the regulatory context, discussion of alternatives, comparisons with similar decommissioning projects in other countries and a description of the organisations involved in work at the FPNC are presented.

3.2.3 Strategy for safety

Overall approach and basic international principles in the organisation of work related decommissioning are presented. Data on the adopted decommissioning strategy and preventive and mitigating measures are given.

The adopted strategy for the decommissioning of RCs and the applied technologies comply with the requirements of the IAEA and the EU, which reflect the advanced principles and modern approaches to the tasks of decommissioning such facilities.

3.2.4 Safety assessment

The safety assessment of the planned activity (dismantling works) was carried out on the basis of technical descriptions of the existing state of structures, systems and components of the main technological building of the FPNC. Moreover, to make a decision on the techniques of dismantling and waste management, consideration was given to the equipment and techniques commonly applied for industrial purpose those were well proven in performing the similar activities for the other nuclear facilities.

A brief description of the work performed in the safety assessment (Sub-activity 4.8), risk analysis (Sub-activity 4.10) and estimation of the transboundary impacts (Sub-activity 4.11) is provided. The following topics were discussed:

- Identification of relevant safety criteria;
- Operational limits and conditions;
- Hazard analysis of normal decommissioning activities;
- Hazard analysis of abnormal events and incidents;
- Assessment of potential consequences;
- Results of the assessment of the effects of non-radiation factors;
- Risk assessment;
- Possible impact of the decommissioning of the RCs on neighbouring countries;
- Comparison of analysis results with relevant safety criteria.

To fulfil the specified requirements, the safety analysis report contains a numerical assessment of the impact on workers and the environment due to exposure factors (radiological and non-radiological) under normal conditions (accident-free) of decommissioning activities and accident conditions. For the analysis of accidents during decommissioning, the deterministic approach to safety assessment recommended by the IAEA experts was applied. This approach to the safety assessment is considered as the most effective method for provision of protection levels for workers and the public during decommissioning activities for nuclear facilities.

The safety assessment report takes into account the adopted decommissioning strategy, as well as the current MTB dismantling organisation plan and technical solutions for the decommissioning of RC. The safety assessment will help develop the final decommissioning project with the possibility of updating the proposed solutions at subsequent stages of project development.

In accordance with IAEA Safety Guide (WS-G-5.2), when developing the safety assessment, the following were performed:

- Justification of compliance with the relevant safety requirements and criteria of the regulatory body to support approval for the proposed decommissioning activities;
- Systematic assessment of the nature, extent and likelihood of hazards and their radiological consequences for workers, the public and the environment in connection with the planned activities and accident conditions;
- The planned and gradual reduction of radiological hazards to be achieved in the course of decommissioning activities, etc. is quantified.

The analysis of normal decommissioning activities and abnormal events and incidents shows that the radiation safety criteria are not exceeded:

- The values of the Limits of doses for personnel and the public as per Radiation Act and Estonian Government Decree No. 97 are not exceeded, both under normal conditions and in accidents;
- There is no need to apply action levels: evacuation, resettlement, as specified in the Estonian Government Decree No. 95.

Under normal work conditions radiation exposure of the population and the environment can occur only due to gas-aerosol emissions into the atmosphere since there are no sources of any significant water discharges during work. Under normal operating conditions, the protection of the public and the environment will be ensured by limiting radioactive releases and discharges to a level not exceeding the release levels specified in the Regulation No. 40 “Conditions for Exclusion and Release of Radioactive Substances Used or Generated in Radiation Operations and Requirements for Requests for Exclusion and Release”.

It is supposed that the radiation criteria for releases and discharges specified in the Regulation No. 40 “Conditions for Exclusion and Release of Radioactive Substances Used or Generated in Radiation Operations and Requirements for Requests for Exclusion and Release” will be met by applying a special work technology, maintaining safety barriers and controlled for compliance by a radiation monitoring system.

Analyses of emergencies defined the scenario with the maximum radiation consequences for the personnel, which assumes the accident "Opening the ionizing radiation source during dismantling inside RC No1". If the source is destroyed, the dose rate at a distance of 1 m will be 1.1 mSv/h. According to estimates, a single individual dose of personnel under the scenario considered will not exceed 0.1 mSv, which is not over the limit of 20 mSv established in the Estonian Government Decree No. 97.

Assessment of the impact of radioactive factors on the general public and the environment under scenarios of emergencies taking into account a conservative approach demonstrated that the exposure dose of the public as a result of radioactive contamination of the territory will not exceed 1.0 mSv/year. Therefore, the survey of radiological conditions including all types of radiation and optimisation of measures aimed at radiation protection at the territories considered is not required.

Since specific radiation can be prevented via protective measures and dismantling technologies planned, there is no need to carry out the protective measures associated with the interference of the normal public life as well as the economic and social activities at this territory.

Possible impact analysis of the decommissioning of RCs on neighbouring countries in accordance with of International Conventions and Treaties was also performed. Simulation of the transboundary transport of radionuclides released in the event of radiation accidents at the FPNC showed that the total effective doses of public exposure during the acute period of the accident and during the first year after it for Finland (at the reference point in Helsinki) will be significantly lower than the established limit of the individual effective dose 1 mSv*year^{-1}.

Calculations of radioactive contamination of the air, the earth's surface, the marine environment and the corresponding doses to the population as a result of the transboundary transport of accidental radioactive releases from the FPNC showed no significant negative effects on the environment and public health. The highest dose that was obtained for the specific meteorological conditions with precipitations accompanied the transfer of radioactive cloud over the Gulf of Finland in a hypothetical beyond design basis accident had the value of 0.01 µSv for 1st year after the accident.

3.3 Synthesis and conclusions

The performed safety assessment allows concluding that the decommissioning technology of the FPNC complies with Estonian and international safety standards.

To exclude uncertainties in estimates associated with possible changes in regulatory requirements, conditions for the implementation of on-site activities taking into account the knowledge gained as a result of other similar work at other facilities or sites (including international experience) and considering the characteristics of equipment to be selected through the design, the safety assessment report should be revised after the development of the final decommissioning design for the FPNC.

3.4 Executive Summary

3.4.1 Initial decommissioning plan

The initial Decommissioning Plan is to describe the planned decommissioning activities of two naval training reactors that are installed at the FPNC and describes the current situation in all areas of activity.

This initial decommissioning plan should be subsequently updated to reflect information on changes of equipment or processes, unplanned events, changes in support capabilities including waste management and radiological monitoring, update of radiological conditions, changes in legislative requirements, changes in financial assumptions and improvements in decommissioning technology, etc.

The decommissioning plan should be finalised approximately three to five years before the safe enclosure phase ends. This final plan will be detailed and will approve by the regulatory body before implementation of the final decommissioning strategy, i.e. decontamination and dismantling. This plan is the basis for the development of the detailed work instructions and procedures.

3.4.2 Safety case

The safety assessment of the planned activity (dismantling works) was carried out on the basis of technical descriptions of the existing state of structures, systems and components of the main technological building of the FPNC. Moreover, to make a decision on the techniques of dismantling and waste management, consideration was given to the equipment and techniques commonly applied for industrial purpose those were well proven in performing the similar activities for the other nuclear facilities.

The analysis of normal decommissioning activities and abnormal events and incidents shows that the radiation safety criteria are not exceeded:

- The values of the Limits of doses for personnel and the public as per Radiation Act and Estonian Government Decree No. 97 are not exceeded, both under normal conditions and in accidents;
- There is no need to apply action levels: evacuation, resettlement, as specified in the Estonian Government Decree No. 95.

The developed safety case and performed safety assessment allow concluding that the decommissioning technology of the FPNC complies with Estonian and international safety standards.

To exclude uncertainties in estimates associated with possible changes in regulatory requirements, conditions for the implementation of on-site activities taking into account the knowledge gained as a result of other similar work at other facilities or sites (including international experience) and considering the characteristics of equipment to be selected through the design, the safety assessment report should be revised after the development of the final decommissioning design for the FPNC.