EVALUATION OF MANAGEMENT ROUTES FOR THE PALDISKI SARCOPHAGI

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ABSTRACT

The necessity to develop the submarine fleet in Russia required constructing a special training base for the training of submarine crews. To this purpose two prototypes of nuclear power units, close analogous to those fitting out nuclear submarines were constructed and commissioned in the sixties on the Navy training centre's base located in Paldiski (Pakri peninsula, Estonia). In 1994, nuclear fuel was discharged from the reactors and transported to Russia while the reactors themselves were prepared for prolonged storage, prior to transfer of the Paldiski facilities to the ownership of the Estonian Republic. The Paldiski facilities are currently being dismantled with the exception of two sarcophagi made of concrete that are housing the two reactor compartments. The question of the future management of both sarcophagi is a key-issue in the cleaning up of the whole Paldiski site. Actually, three basic questions should answered: when should dismantling operations occur, how this should be done, and what could be the corresponding cost.

Within the context of enlargement of the European Union, the Commission services (first Directorate-General for Environment and then Directorate-General for Enlargement) decided to support Estonia to respond to these three questions through a study contract that was awarded in 1999 to a TECHNICATOME / BNFL consortium.

The work scope was made up of three distinct tasks :

- Data collection regarding the nuclear reactors and enclosing compartments design, and the works carried in order to prepare the reactor compartments for long-term storage.
- Drawing up dismantling strategies in order to reach the third decommissioning level defined by IAEA.
- Evaluation of these decommissioning options on the basis cost estimation and radiological impact evaluation, in view to recommend the best management route.

This article gives the key stages and the conclusions of this study.

INTRODUCTION

The necessity to develop the submarine fleet in Russia required constructing a special training base for the training of submarine crews. To this purpose two prototypes of nuclear power units, close analogous to those fitting out nuclear submarines were constructed and commissioned in the sixties on the Navy training centre's base located in Paldiski, 20 miles West to Tallinn (Pakri peninsula, Estonia).

Fig. 1. Paldiski main building (on the right)is sheltering the two Reactors Compartments

An agreement between Government of the Russian Federation and Government of Estonian Republic was signed on July 30, 1994, for transfer of the Paldiski Navy Training Centre, with laid-up nuclear reactors and nuclear waste storage facilities, to the ownership of the Estonian Republic. According to this agreement, nuclear fuel was discharged from the reactors and transported to Russia while the reactors themselves were prepared for prolonged storage, and surrounded by 400 mm thick concrete shelters, called sarcophagi.

Fig. 2. Erection of the sarcophagus around the reactor Compartment #2, 1995

A study contract was awarded in 1999 by the European Commission to a TECHNICATOME / BNFL consortium involving the Russian Institute VNIPIET, designer of the nuclear reactors and sarcophagi, and AS ALARA Ltd, the Estonian operator of the site. The aim of this study is to identify :

- remaining uncertainties concerning the way the Russian side carried out this enclosure process and consequently in predicting dismantling operations,
- feasible rational routes for the decommissioning of both nuclear power units, according to the in progress Estonian regulations regarding radiation protection and radioactive waste management and the IAEA recommendations.

The work scope was made up of three distinct tasks :

- Data collection from the Russian Institute VNIPIET, regarding the nuclear reactors and enclosing compartments design, the nuclear reactors operational history, and the works carried out by the Russian Navy and the VNIPIET Institute before transferring the site to the ownership of the Estonian Republic.
- Drawing up dismantling strategies in order to reach the third decommissioning level defined by IAEA, after a possible storage period in order to lower the remaining activity.
- Evaluation of these decommissioning options on the basis cost estimation and radiological impact evaluation, in view to recommend the best management route for the Paldiski sarcophagi.

DATA COLLECTION

The Russian design institute VNIPIET designed the complex of buildings and premises in which the power stands were located and, later on, the general concept and of Paldiski sarcophagi. Several Russian design and development organisations were involved in designing the training power stands including :

- the engineering bureau CDB ME «Rubin», which was involved in preparation of stands 346A and 346B for prolonged storage,
- the research and development institute RDIPE, which designed the first nuclear powered unit,
- the engineering machine-building bureau OKBM, which designed the second nuclear powered unit.

All these organisations were involved in tasks 1, 2, and 3 of this project as LI VNIPIET's subcontractors.

Power unit #1 (stand 346A) is close analogous of those fitting out the first generation of Russian nuclear powered submarines (Echo class). It enclosed a PWR/VM-A type reactor of 70 MW thermal capacity which was in operation from April 1968 to January 1989. In the early eighties an extension was added to the main building, and the stand 346B was constructed inside. It enclosed a PWR/VM-4 type reactor of 90 MW thermal capacity, which was in operation from February 1983 to December 1989. Both reactors were operated without major failure for the entire service life.

Spent fuel assemblies have been removed from the reactors in August-October 1994 and transported to Russia, and then works have been carried out to put the reactor compartments in prolonged storage. On completion of these works, their equipment and systems are in the following condition :

1 The reactors are closed with the standard cover welded to the reactor body.
2 All holes in the reactor cover are plugged with welded plugs.
3 The reactors have been emptied and have an atmospheric pressure inside.
4 All the systems of the compartments, pipelines, tanks, vats and the hold have been emptied as prescribed by standards. The equipment, pipelines and tanks contain "dead" remaining water stock in the 1st, 2nd, 3rd and 4th loops amounting to about 1370 litres for unit #1 (360 litres inside the primary circuit), and 2285 litres for unit #2 (600 litres inside the primary circuit).
5 High pressure gas and air have been removed from cylinders and systems of the reactor compartments.
6 Sorbents have been removed from filters of the 1st, 2nd and 3rd loops.
7 All pipelines connected with the system of the 1st loop and the draining/drying system are plugged with welded plugs.
8 To ensure tightness of the reactor compartment of the stand during the whole period of storage and to provide the second safety barrier, plugging of holes and cut-outs on the main body of the reactor compartment and its end bulkheads has been carried out.

  After tightness testing, the outside surfaces of the body and the bulkheads of the reactor compartment, platforms, gangways and guard railings were painted.
9 Durability of the reactor compartments bodies prepared for prolonged storage is designed for maximum design earthquake of magnitude 7 by MSK-64 scale.

In order to meet the requirement for prevention of physical access to the equipment of the steam producing plants, placement of concrete around some items and body structures of the reactor compartments was carried out (see general view of RC #1).

During laying-up stage of RC #1, concrete was placed :

- onto the reactor cover in the fore equipment space: 4.7 m^3.
- into the primary circuit room: 17.65 m^3,
- on the roof of the U-shaped space: 7.5 m^3,
- on the hatch located above the port side steam generator space: 0.9 m^3.

During laying-up stage of RC #2, concrete was placed :

- onto the roof of the metal-water protection tank: about 9.0 m^3
- on the deck of the upper room of the equipment space: about 31.0 m^3,
- on the hatches of the decks of port side and starboard side pump spaces: about 1.2 m^3 (for both hatches).

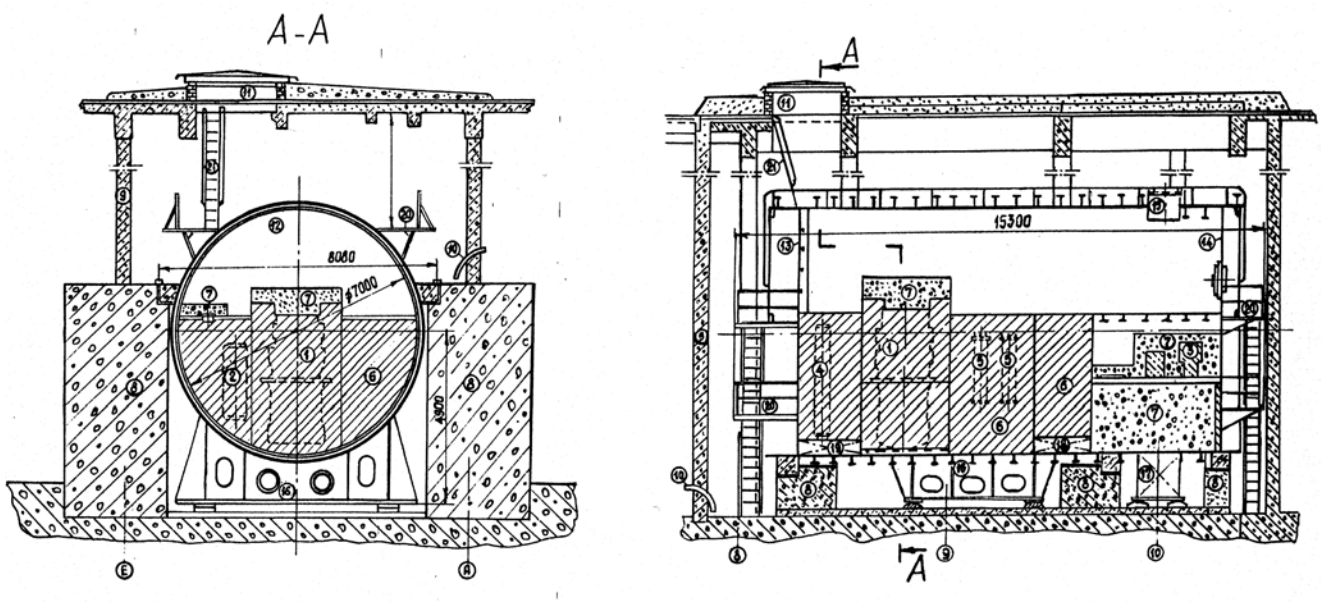

Fig.1 Reactor compartment № 1. Cross and longitudinal sections.

1 - reactor; 2 - steam-generator; 3 - 1 circuit pump; 4 - pressurizer; 5 - coolant purification filter; 5 - non-attended rooms; 7 - new-placed concrete in RC; 8 - concrete shielding wall; 9 - vault wall; 10 - penetrations in the vault for control measurements; 11 - manhole into the enclosure; 12 - RC vessel; 13,14 - cross partitions; 15 - manhole to RC; 16 - metal supports; 17,18,19 - tanks; 20 - passover landing; 21 - trap.

Fig. 3. General view of the Reactor Compartment #1

A certain amount of radioactive waste was stored in both reactor compartments. In the initial version of the decommissioning project, it was not planned to store radioactive waste into reactor compartments. But it was necessary to do that, because Russian teams had a very short time to deal with these radioactive wastes, and there was no free storage area within the site. The total weight of waste stored in RC #1 is 14 tons or so. The total weight of waste stored in RC #2 is 2.5 tons or so.

According to the lists of wastes included in the files given to Estonian authorities when transferring the ownership of the site, most of the wastes stored are miscellaneous low level radioactive wastes with surface contamination. But some radioactive sources were also put into concrete poured into the reactor compartment #1. These sources were used for calibrating radiological measurement equipment. This work was carried out in a very short time, and the only pieces of information we have about it are the lists above mentioned. It is not possible to indicate the exact location of these radioactive sources.

Presently the sarcophagi itself are in quite stable state, with no visible cracks or other major defects. In regard to results of compression strength measurements of samples taken from the walls of sarcophagi #2, the walls are made of high quality and strong concrete. But the sarcophagi around reactor units were constructed without ventilation, humidity control, any alarm or monitoring systems etc....

The predictions of enclosed activity in the reactor compartments have been provided for the years 1999, 2039 and 2089 (10, 50, 100 years after shutdown). Highly activated components are reactor vessel with jacket and screen, the internals parts of the reactor with the compensating grid and control rods, and Iron and Water Shielding tank (IWS tank). All other structures located outside the reactors and IWS tanks are characterised by significantly lower induced activity. According to the analysis carried out, the accumulated activity of long-term radionuclides in Nuclear Powered Units materials are summarised in the table below :

Table I. Summary of accumulated activity of long-term radionuclides

NPU	Date	1999	2039	2089	Key radionuclides
	Delay time after shutdown (year)	10	50	100	
Stand 346 A	Total activity (TBq)	362 TBq	69 TBq	47 TBq	^{55}Fe, ^{60}Co, ^{63}Ni, ^{59}Ni
Stand 346 B	Total activity (TBq)	144 TBq	13.3 TBq	9.6 TBq	^{55}Fe, ^{60}Co, ^{63}Ni, ^{152}Eu, ^{154}Eu

DRAWING UP OF DISMANTLING OPTIONS

TECHNICATOME's experience in the field of submarines reactors decommissioning is based on the studies and works carried out for three reactors :

- The first French nuclear submarine named Le Redoutable was shut down in 1991, and reached decommissioning level 1 in 1992, and level 2 in 1993.
- The first land based prototype named PAT, and located in Cadarache, in the south of France, was shut down in 1993, and reached decommissioning level 1 at the end of 1994.
- The second French nuclear submarine named Le Terrible was shut down in1996, and reached decommissioning level 1 in 1997, and the works to reach level 2 are in progress.

The strategy that was selected for the decommissioning of these nuclear reactors was the following :

1. Dismantle up to level 2 as soon as possible, to reduce operation costs and to reach a high safety level.
2. Wait 50 years (10 times Co-60 half period) in a temporary storage area in order to lower gamma dose rates inside the compartment, with a strict safety policy.
3. Dismantle up to level 3, sorting the arising waste and packaging radioactive waste in special containers.
4. Transport of these containers to the French repository named Centre de l'Aube (300 years near ground surface disposal).
5. After 300 years, free release of the Centre de l'Aube storage area.

On the basis of a comparison between :

- the description of the storage conditions of the decommissioned French nuclear submarines reactor compartments,
- the data about the Paldiski Reactor Compartments collected in the course of the first task of the project,

an evaluation of the current storage conditions of the Paldiski reactor compartments was assessed regarding the risk of radioactivity dispersion, taking into account :

- the fire risk,
- the presence of miscellaneous radioactive waste in the reactor compartments,
- the provisions that have been made against humidity effects regarding primary circuit and reactor compartment corrosion risk (Paldiski reactors primary circuits can't be considered as reliable confinement barriers for more than 50 years at the very best),
- the necessity of checking up the efficiency of radioactivity confinement provisions.
- the flood risk.
- the reliability of reactor compartments shell as first confinement barrier for a few years (at the present time, it's not possible to guarantee the reliability of this barrier for 50 years).
- the reliability of sarcophagi as the second confinement barrier (with eventual complementary safety provisions).

This evaluation has highlighted some deficiencies regarding safety. Considering the high level of activation of reactor compartment #1 and the lack of arrangements to control corrosion and flood risk, it's not possible to reasonably exclude the risk radioactivity dispersion for the next 50 years.

From the above evaluation of the Paldiski Reactor compartments storage conditions, suitable strategies were selected :

- **First Strategy** : **Final disposal of the reactor compartments as a whole**
  - Option #1 : in a near surface disposal facility located on the Paldiski site.
  - Option #2 : in situ, in the sarcophagi, avoiding RC removal operations.
- **Second Strategy:** **Full dismantling of the reactor compartments after a storage period of 50 years to 100 years for radioactive decay.**
  - Option #1 : Minimising cutting works in order to lower men exposure.
  - Option #2 : Decontamination and cutting components into small pieces in order to sort wastes, in view to reduce the resulting waste volume (including the possibility of melting devices).

The applying regulations are the in progress Estonian regulations regarding radiation protection and radioactive waste management, and also the IAEA recommendations. An overview of the development of Estonian regulations regarding radiation protection and radioactive waste management is given the report in reference <4>.

These decommissioning strategies are briefly described below :

1. <u>First decommissioning strategy option 1 : Final disposal of the reactor compartments as a whole in a near surface disposal facility located on the Paldiski site.</u>

Another project supported by the European Commission has been launched to define the criteria in order to choose a suitable site and to decide what type of repository would be constructed in Estonia. Six possible locations have been identified, all located along Estonia northern cost.

The use of a B type container for radioactive waste transportation is obligatory beyond an "A2" activity limit imposed by European transportation rules for radioactive goods (ADR). This A2 value depends on the radionuclides attached to the waste transported. We calculated this activity limit for the year 1999, 2050, and 2100, in the case of Paldiski reactor compartment #1 and reactor compartment #2. It appeared that Paldiski reactor compartments must be transported at the moment in a B type container, due to their total enclosed activity. But designing a B type container for components as big as reactor compartments is quite impossible. RC#2 may be transported in a container A type after the year 2030. RC#1 may be transported in a container A type <u>only after the year 2165</u>.

Furthermore, the size (8 x 12 x 9 m) and weight (1000 tons or so) of reactor compartments are very high, and it appears that Pakri peninsula roads characteristics are not convenient to transport the reactor compartments as a whole from Paldiski site to a disposal site which would be located in another area. And there's no suitable infrastructure on the Paldiski site to allow the shipping of the reactor compartments. For these reasons, we have assumed that the repository is located on the Paldiski.

This decommissioning option rests on the following steps :

- Filling the primary circuit with concrete, in order to stabilise waste, and extracting as much as possible flammable materials stored in reactor compartments
- Erecting a new building on the Paldiski site designed for both reactor compartments disposal, according to IAEA requirements for the design of near surface repository for low and intermediate level waste.
- Building a special heavy-duty route between the sarcophagi and the new disposal building.
- Transferring the reactor compartments as a whole from the sarcophagi to the new building.
- Implementing a surveillance program in order to check the efficiency of the above measures.

The transportation in safe conditions of high size and high weight items requires specific equipment and know-how. Technicatome as gained a great experience in such operations, at the occasion of the first French nuclear submarine named Le Redoutable decommissioning operations.

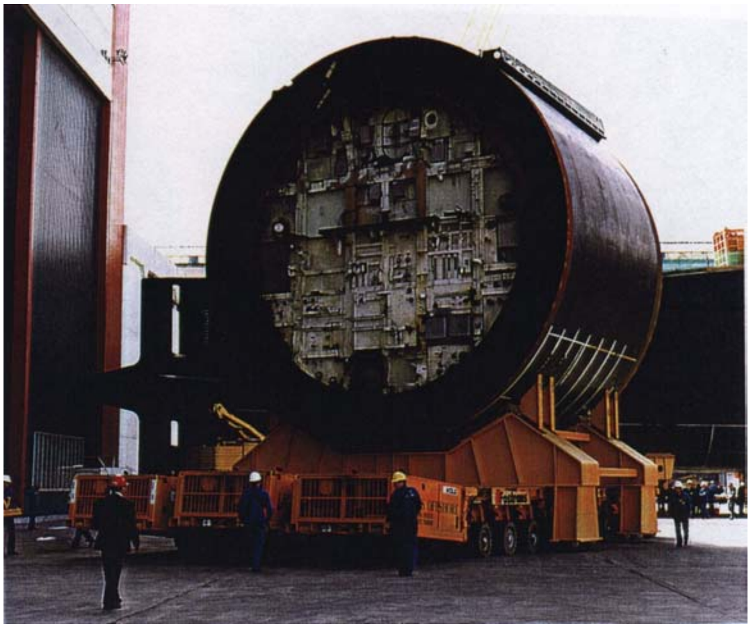

Fig. 4. Transferring "Le Redoutable" reactor compartment to the long term storage building, 1992.

The main advantage of this scenario is to allow standardised disposal conditions without implying high men exposure, and without prior storage period for radioactive decay. But the waste packages (the reactor compartments) are not fully compliant with IAEA recommendations regarding waste management.

2. <u>First decommissioning strategy option 2 : Final disposal of the reactor compartments as a whole in situ, in the sarcophagi, avoiding compartments removal operations</u>

The main difficulties to remove and to transfer the reactor compartments as a whole to the repository are :

- the opening of the sarcophagi without any damage for the reactor compartments,
- the handling of the reactor compartments from the sarcophagi to the disposal site.

The handling of the reactor compartments would require to fit out the Paldiski site with heavy infrastructure. These difficulties induced us to consider another scenario, which consists in reinforcing sarcophagi with the aim to transform them in small final disposal sites, in accordance with Estonian regulations.

This strategy is based on civil engineering techniques also envisaged in the course of other projects : the ICC Consortium, that involves both TECHNICATOME and BNFL, has studied possible scenarios for reinforcing and stabilising Chernobyl sarcophagus, in the course of SIP Project (Shelter Implementation Program) supported by G7.

For final disposal with a monitoring facility for a time span of the order of 300 years, the soil should present the following main characteristics:

Geology:
The region chosen must present geological characteristics with satisfactory impermeability at very great depth. This is generally the case for deep formations of the Lower Cretaceous Age, which are most often covered with layers of soil of the marl-limestone, clay marl and clay-sand types.

Geotectonic:
A structural sketch map will be drawn to define the organisation of the major underlying structural fields. The region and site must not present major accidents, faults, cleavage, tilting of strata, or potential landslides likely to result in the disintegration of the bedrock and underlying soil formations.

Hydrology:
The position of the upper bed of the water-bearing system must be below the clay layer covering the draining layers of sand and gravel. The arrangement of layers in relation to one another reduces the permeability of the upper part of the subsoil, so that both water originating from infiltration and either surface run-off water or groundwater likely to rise inside the disposal structures can be confined and drained away.

Water currents in the groundwater or streams must provide draining for excess water due to variations in the groundwater level or streams of run-off water resulting from soil infiltration. It is essential that these natural outflows exist so that the groundwater level remains relatively constant. In any case the groundwater must not be confined.

The data summarised in the survey reference <5> shows that the Pakri Peninsula could be a convenient area, but this fact should be confirmed on the basis of a specific survey.

The works to be carried out in order to transform the sarcophagi in small final disposal sites are summarised below :

- Soil, geological, geotectonic and hydrological surveys on the possibility of permanent in-situ disposal,
- Extracting as much as possible flammable materials stored in reactor compartments,
- Fitting out reactor compartments and sarcophagi with an air conditioning system in order to provide against corrosion,
- Filling the primary circuit with concrete, in order to stabilise waste and immobilise radionuclides.

- Sarcophagi strengthening :
    - Raft and earth works to ensure stability of the building, and to provide against flood. A waterproofing system has been proposed for the layer below the raft consisting of injecting fine rendering cement mortar and bentonite cement grout to a thickness of roughly 5 meters under the raft. The pressure-, volume- and flow-controlled injections are made through a casing network crossing the raft and injection pipes of variable length and fall. This injection operation would be carried out by lowering the groundwater level in two or three stages. To complete this waterproofing system, we recommend that a continuously cast reinforced concrete slab is laid on top of the existing raft with a High-Density Polyethylene (HDPE) membrane separating them.
    - Works to waterproof the sarcophagi and to reinforce their superstructure. The sarcophagi walls should be lined with skins from base to roof level. These skins would be supported and anchored at the base in the raft and on the supporting ledges of the sarcophagi runners. The roof cover should be made impervious to rainwater by a built-up system comprising an HDPE membrane laid on the existing roof slab separated by a geotextile film. Containment should be provided by 2 HDPE films applied either side of the sarcophagus walls.
- Implementing a surveillance program in order to check the efficiency of the above measures. This surveillance program of reactor compartments and sarcophagi should be in force for a minimal period of 300 years.

The main advantage of this scenario is that it allows quite safe disposal conditions, without requiring handling operations of the reactor compartments, and without requiring carrying out dismantling works which would imply high men exposure. Moreover, it does not prior storage period for radioactive decay. But as for the first option, the waste packages (the reactor compartments) are not fully compliant with IAEA recommendations regarding waste management.

3. Second decommissioning strategy : Full dismantling of the reactor compartments

The influence of the storage period is significant regarding men exposure considering this dismantling strategy, as hand-on dose rates close to reactor compartment components is quite high, especially regarding the reactor vessel. However, after a 50 years storage period, the decrease of gamma dose rate will be much slower, as spectrum repartition shows that Co-60 is the most significant gamma high-energy radionuclide (half-life is 5.3 years). In the year 2050, Co-60 activity will have decreased one thousand times, and the total men exposure for the dismantling operations will be nearly one hundred times lower.

Between 2050 and 2100, the decrease of gamma dose rate will be ten times lower than between reactors shutdown and 2050. Waiting 100 years before implementing this second decommissioning strategy brings no significant advantage, but implies additional cost to guarantee the reliability of the confinement barriers for the whole storage period. As a consequence, we recommend that this second decommissioning strategy would be implemented after a storage period of 50 years.

The framework can be resumed as follows :

- Restoration of standardised storage conditions for the storage period :
  - Improvement of reactor compartments resistance against corrosion, by the mean of a ventilation system.
  - Main building and Sarcophagi strengthening, and improvement of sarcophagi confinement properties resistance against flood.
- During the storage period, the following works should be performed :
  - Building of the Estonian radioactive waste surface storage site.
  - Building of a "packaging workshop" in the main building, and upgrading of the 50 tons crane lift.
- Complete dismantling of the reactor compartments into pieces to be transferred to the "packaging workshop". A remote control device for pipelines automated cutting in high exposure areas has been developed in Russia. Such equipment could be used to cut off steam generators from the reactor vessel.
- Packaging of the arising radioactive waste. Two different options should be considered :
  - <u>Option n°1</u>: Making special waste packages minimising cutting works.

    The waste packages are made from whole Nuclear powered units systems like reactor vessel, steam generator vessels, etc, minimising cutting works, in order to simplify the dismantling operations and to lower men exposure.
  - <u>Option n°2</u>: Minimising the volume of definitive wastes.

    The aim of this packaging option is to minimise the final volume of waste, using techniques like decontamination, compaction, or recycling by the mean of melting devices.
- Release of the site after transferring the waste packages to disposal and dismantling the sarcophagi and main building.

The main drawback of this scenario is that it's a long-term strategy, requiring heavy works that could imply high men exposure. But regarding waste management, it's a very effective strategy, which result in a full compliance with IAEA recommendations.

EVALUATION OF THESE DECOMMISSIONING OPTIONS AND CONCLUSION

The cost evaluation was carried out considering western Europe man-month rates for design and Estonia man-month rates for on site works. Necessary equipment for transferring the reactor compartments as a whole from the sarcophagi to the disposal site building is considered to be rented from the Tallinn shipyard. Other equipment is considered to be bought in western Europe.

On these basis, the following decommissioning strategies have been evaluated :

- First strategy, first option (final disposal of the reactor compartments in a near surface facility).
- First strategy, second option (final disposal of the reactor compartments in situ, in the sarcophagi).
- Second strategy (full dismantling of the compartments after a storage period for radioactive decay).

In the case of the second strategy, it could be possible to further reduce the volume of waste for disposal of 20% or so using in-situ decontamination of the reactor coolant circuits (packaging option #2). But It appears that using in-situ decontamination is not cost effective in the particular case of Paldiski facilities decommissioning, as the necessary investment is very high and the total waste volume too low to written off the investment cost. The use of melting of the resulting waste could allow to reduce their volume of 20% to 30% The total cost of radioactive waste packaging would be reduced in the same ratio. Whether melting is a cost effective approach will depend on many factors and an economic evaluation will need to be carried out to establish the answer. Experience in other European countries gives some indications that it may be a cost-effective approach, though the whole picture needs to be taken into account.

The different strategies drawn up appears to be deeply different. The result of their implementation would be quite different, and their estimated cost is also quite different :

- the cost of the first strategy, first option (final disposal in a near surface facility), is one plus half as much as the cost of the second option (final disposal in situ, in the sarcophagi),
- the cost of the second strategy (full dismantling after a storage period for radioactive decay) is three times as much as the cost of the first strategy, second option.

From a strictly technical angle, the three strategies would result in an acceptable situation regarding its radiological impact. The risk of radioactivity release during the decommissioning operations and after their completion appears to be low. Moreover, men exposure induced by dismantling operations is acceptable for all the three options (from 300 men.mSv for the first strategy to 1800 men.mSv for the second strategy). So the most cost effective strategy to reach a safe situation seems to be the first one.

At present there is no waste acceptance criteria for disposal established in Estonia for this specific radioactive waste. Therefore, pending the adoption of Estonian criteria, the following recommendations are suggested.

The first strategy does not result in a total compliance with IAEA recommendations regarding radioactive waste disposal. As regulations regarding radioactive waste disposal are fully consistent with IAEA recommendations in Western Europe, the implementation of the first strategy drawn up in this report would not be allowed in France or Great Britain for instance.

Even if the first strategy could be compliant with the in progress Estonian regulations regarding radioactive waste management, the European Community enlargement process will inevitably result in regulations (or recommendations) evolutions towards a same standard. As a consequence the choice of the first strategy could be called into question in a middle term or long term. In case of full dismantling works carried out after the implementation of the first strategy, the total cost would be above the sum of the individual costs of each strategy.

From this review of the decommissioning options both TECHNICATOME and BNFL recommend the full dismantling of the Paldiski reactor compartments, after a storage period of 50 years. It will be necessary to carry out improvements to the Sarcophagi to ensure the continued safe storage of the reactors for this period of time. To assist with carrying out the dismantling option after 50 years a plan which not only reviews the decommissioning in detail but also the costs involved with this. Whilst this plan is being prepared the impact of the costs on the Estonian economy must also be considered. If these costs identified are too great for the Estonian economy to bear then the option of the final disposal of the reactors compartments in situ would probably have to be implemented.

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