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CONTRACT B7-5350/99/6141/MAR/C2

EVALUATION OF MANAGEMENT ROUTES FOR THE PALDISKI SARCOPHAGI

TASK 3 – EVALUATION OF DISMANTLING STRATEGIES

FINAL REPORT

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A. *SUMMARY (AND/OR MAIN CONCLUSIONS) :*

Contract Number :	B7-5350/99/6141/MAR/C2
Title :	Evaluation of management routes for the Paldiski sarcophagi
Contractor :	TECHNICATOME – BNFL
Subcontractors :	AS ALARA Ltd – LI VNIPIET Institute
Objectives and scope of this project :	Task 1 - Data Collection and analysis Task 2 - Drawing up of potential dismantling strategies Task 3 - Evaluation of dismantling strategies
Progress of work to date :	Completion of Task 3 and final report
Period covered :	March 2001 to July 2001
Objectives and scope of Task 3 :	Task 3 – Evaluation of decommissioning strategies : – Cost estimation, – Radiological impact evaluation. Recommendation of the most convenient decommissioning strategy

The aim of this contract is to identify feasible rational routes for the decommissioning of two nuclear power units of the former RF Navy Training Centre on the Pakri peninsula in Estonia. The main purpose of task 3 of this project is to evaluate, on the basis of cost estimations and radiological impact evaluation, the decommissioning strategies that were drawn up in the course of task 2 of the project (see second intermediate reference <2>), and to recommend the most convenient one.

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 second intermediate report (see reference <2>).

The decommissioning strategies studied in the course of Task 2 are listed below :

- **Strategy #1** : **Final disposal of the Reactor Compartments as a whole**
  - Option #1 : in situ, in the sarcophagi, avoiding Reactor Compartments removal operations.
  - Option #2 : in a near surface disposal facility located on the Paldiski site.
- **Strategy #2:** **Full dismantling of the Reactor Compartments**
  - 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 (using or not melting devices).

The main advantages and drawbacks of each decommissioning option have been studied and synthesised in the following table.

Decommissioning Strategy	Advantages	Drawbacks
First Decommissioning Strategy Disposal of the RCs as a whole	– Except radioactive sources extraction, the works to be carried out would not imply high men exposure. – The risk of radioactivity release into the environment is reasonably low.	– Waste packages (RCs) are not consistent to IAEA recommendations regarding waste management – Waste packages are not totally immobilized into the final disposal.
Decommissioning Option 1 In situ disposal in the sarcophagi	– This option does not require heavy dismantling works. – As a consequence, the global cost would be quite low. – No radioactive waste transport is required.	
Decommissioning Option 2 On-site near surface disposal at Paldiski	– Reactor compartments transfer to the disposal building could be considered as a radioactive waste transport, but this radioactive waste (the reactor compartments) remains on the Paldiski site.	– This decommissioning option requires heavy works to transfer the RCs into the disposal building. – As a consequence, the global cost would be much higher than for option #1. – The Reactor Compartments transfer is not fully consistent to the radioactive waste transport regulations due to their total enclosed activity, but as the waste packages are transported on tens of meters with no exit of the Paldiski site, this option seems to be reasonable.

Decommissioning Strategy	Advantages	Drawbacks
Second Decommissioning Strategy Full dismantling of the RCs	– Waste packages are consistent to the IAEA recommendations regarding waste management. – Waste package (parallelepipeds) will be totally immobilised into the final disposal. – Waste packages transport to the disposal site is fully consistent with Estonian regulations and IAEA recommendations regarding radioactive waste transport, except for RC#1 reactor vessel (but RC#1 reactor vessel transport could be reasonably performed, providing eventually some complementary safety measures)	– This decommissioning strategy requires heavy works to dismantle the Reactor compartments. These works imply a very high labour, and a quite high total men exposure. – As a consequence, the global cost would be higher than for first strategy. – The risk of radioactivity release into the environment is reasonably low, but higher than for the first strategy.
Packaging Option 1 Disposal of big components as specific waste packages	– Total men exposure is lower than for packaging option #2	– The resulting waste volume is higher than for packaging option #2
Packaging Option 2 Minimising the waste volume by decontamination, recycling, etc ..	– The resulting waste volume is lower than for packaging option #1	– Total men exposure is higher than for packaging option #1

The results of cost estimation and total dose evaluation are summarised in the table below :

	Duration of decommissioning works (years)	Total Dose (h.mSv)	Dose per man per year (mSv/man/year)	TOTAL COST (M EURO)	TOTAL COST (M EEK)
FIRST DECOMMISSIONING STRATEGY : FINAL DISPOSAL OF THE REACTOR COMPARTMENTS AS A WHOLE					
Option 1 : Final disposal of the Reactor compartments in their sarcophagi	2,8	328	7,9	5,2	81,5
Option 2 : Final disposal of the Reactor Compartments as a whole in a repository located on the Paldiski site.	5,8	555	5,2	7,6	119
SECOND DECOMMISSIONING STRATEGY : COMPLETE DISMANTLING OF THE REACTOR COMPARTMENTS					
Waste packaging option 1 : Making a few big definitive packages	6,6	1780	9,6	14,1	221

The cost estimation of the second strategy – Waste packaging option 2 (Minimising the waste volume using decontamination or recycling by melting) has not been mentioned in the above table for the following reasons (See section 3.2.2):

- 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.
- Whether recycling by melting is a cost effective approach depends on many factors. Experience in other European countries does not allow to answer surely to this question, though the whole picture needs to be taken into account. In particular Estonia should consider a possible agreement with a foreign country operating a melting facility.

As a conclusion, the different strategies drawn up appear to be deeply different. The result of their implementation would be quite different, and the estimated cost of the most expensive strategy is nearly three times as much the cost of the less expensive 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 strategies. So the most cost effective strategy to reach a safe situation seems to be the first one.

But as shown by the table which summarises the main advantages and drawbacks of each option, 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 progress Estonian regulations regarding radioactive waste management, the European Community enlargement process will inevitably result in regulations 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.

For these reasons, we recommend the full dismantling of the Paldiski reactor compartments, after a storage period of 50 years.

The cost of sarcophagi reinforcements and improvements that are necessary to ensure the safety of the 50 years storage period before carrying out dismantling works has been estimated to EUR 700 000 (EEK 36 million) for both sarcophagi. These works should be implemented as soon as possible.

After that, a founding plan should be drawn up in order to carry out the full dismantling of the reactor compartments after the 50 years storage period. If unfortunately this choice appears to be financially unrealistic for Estonia, the final disposal of the reactor compartments in situ, in the sarcophagi, should be implemented.

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B. ATTRIBUTES :

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D. MODE OF DISTRIBUTION :

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- ☐ *standard distribution*

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Rev. A : First issue

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CONTENTS

List of References

<1> Evaluation of management routes for the Paldiski sarcophagi – First intermediate report.
Task One : Data collection.
TECHNICATOME report TA-141586 Ind. A.

<2> Evaluation of management routes for the Paldiski sarcophagi – Second intermediate report.
Task Two : Drawing up of dismantling strategies.
TECHNICATOME report TA-215194 Ind. B.

<3> Evaluation of management routes for the Paldiski sarcophagi – First progress meeting minutes.
TECHNICATOME report TA-144666.

List of abbreviations

ACP	Auxiliary Coolant Pump
AF	Activity Filter
CACP	Cooler of Auxiliary Coolant Pump
CDB	Central Design Bureau
CMCP	Cooler of Main Coolant Pump
CPS	reactor Control Protection System
ERPC	Estonian Regulation and Protection Center
IWP	Iron-Water Protection
LWSB	Liquid Waste Storage Building
LWTF	Liquid Waste Treatment Facility
MCP	Main Coolant Pump
MTB	Main Technological Building
MWP	Metal-Water Protection
NPP	Nuclear Power Plant
NPU	Nuclear Powered Unit
NS/M	Nuclear Submarine
NSSS	Nuclear Steam Supply System
PIERG	Paldiski International Expert Reference Group
SG	Steam Generator
SPP	Steam Producing Plant
RC	Reactor Compartment

<u>Note :</u>
The Excel tables and pictures included in appendices were reduced in order to be printed on paper of standard format. All the digital files are available on the attached CD-ROM.

1 GENERAL

1.1 BACKGROUND

The necessity to develop the submarine fleet in Russia required constructing a special training base for a preliminary training of submarine crews made most realistic in conditions. To this purpose two prototypes of nuclear power units (NPU), close analogous of NPU installed at nuclear submarines (NS/M) were constructed and commissioned in the sixties on the Navy training centre's base located on the Pakri peninsula in the town of Paldiski (Estonia).

According to an agreement between Government of the Russian Federation and Government of Estonian Republic of July 30, 1994, for transfer of this training facility of Navy Training Centre located in Pakri Peninsula (town of Paldiski), with laid-up nuclear reactors and nuclear waste storage facilities to the ownership of Estonian Republic. Nuclear fuel was discharged from the reactors and transported to Russia while the reactors themselves were prepared for prolonged storage.

A number of uncertainties remain concerning the way the Russians carried out this enclosure process and consequently in predicting dismantling operations.

The other site buildings consist mainly of a liquid waste treatment plant, a decontamination plant, liquid and solid waste stores, a radiochemical laboratory, each of them being in poor shape. Important work is being done through PIERG (Paldiski International ExpeRt Group) members to clean up the site and to start building new waste packaging and storage facilities.

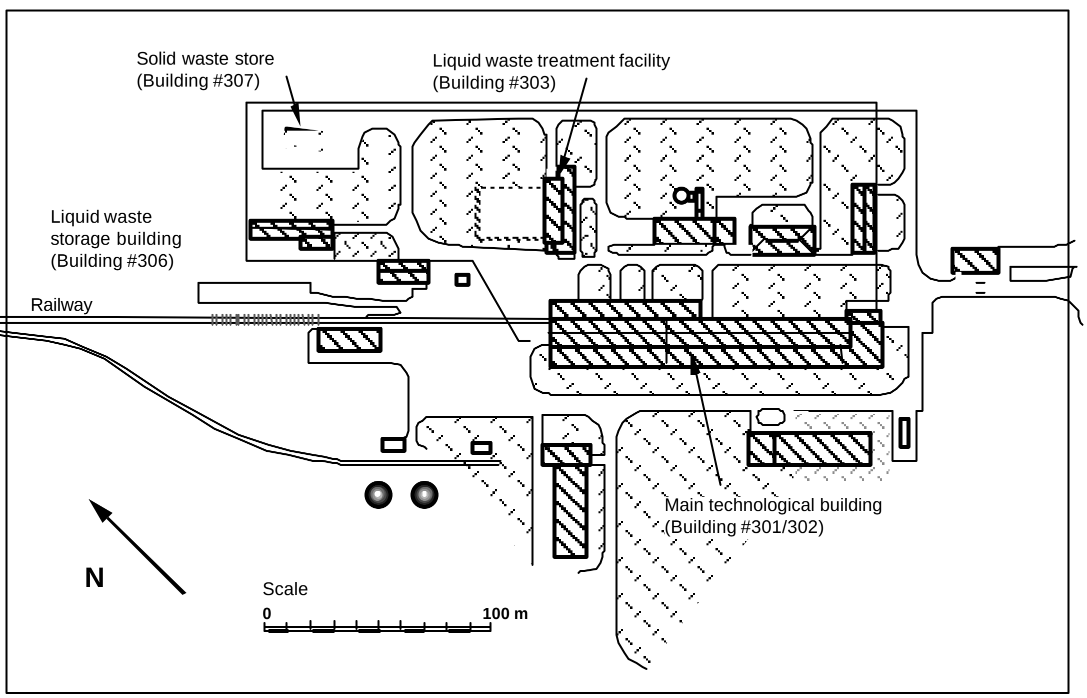

Figure 1 - Paldiski site plan

1.2 PRESENTATION OF THE PROJECT

The main purpose of this contract is to identify feasible rational routes of dismantling and complete removal of radioactive components from two nuclear power units of the former RF Navy Training Centre on the Pakri peninsula in Estonia.

This study will be made up of three different tasks:

- Task 1 : Data collection analysis
- Task 2 : Drawing up of potential Dismantling strategies
- Task 3 : Evaluation of Dismantling strategies

This report is the final report of the study: it presents the results of the third task of the project.

1.3 INVOLVED PARTIES

The two companies TECHNICATOME and BNFL have joined to perform this study, with the main aim to define the best dismantling route for the Paldiski sarcophagi, regarding cost and radiological impact on the environment, in accordance with IAEA safety recommendations and Estonian radioactive waste management regulations. TECHNICATOME has been the leader of the contract.

Two subcontractors have been involved in this study :

- The Russian design institute VNIPIET, which designed the complex of buildings and premises in which the power stands were located and, later on, the general concept of NPU decommissioning and sarcophagi design,
- The Estonian Waste Management Agency AS ALARA, which is responsible for the site.

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 346A unit,
- the engineering machine-building bureau OKBM, which designed the 346B unit.

All these organisations were involved in this project as VNIPIET's subcontractors.

1.4 TASK 1 : DATA COLLECTION

The main purpose of task 1 of this project was to collect the maximum available information about :

- The two nuclear reactors,
- The two sarcophagi,
- The work carried out when the two reactors were shut down, and when erecting the sarcophagi,

- The existing and foreseen waste conditioning equipment available on the Paldiski site that could be used to carry out dismantling work.

We analysed this data owing to our know-how in the field of nuclear propulsion reactors, and we compared the information provided by the VNIPIET Institute to the data we have about the land based prototypes reactors that TECHNICATOME operates in Cadarache, especially about the PAT Nuclear Power Unit. This reactor is the first French land based prototype of nuclear power units installed in French nuclear submarines. PAT Nuclear Power Unit was constructed and commissioned in the early sixties in Cadarache in the south of France, and decommissioned in 1992. TECHNICATOME began the dismantling process in 1993, and the level 1 of the three decommissioning levels defined by IAEA was reached at the end of 1994.

The data collected in the course of task1 is detailed in the first intermediate report reference <1>.

1.5 TASK 2 : DRAWING UP OF DISMANTLING STRATEGIES

The main purpose of task 2 of this project was to draw 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. These three decommissioning levels are as follows :

- level 1 : the reactor is defueled, circuits are drained and confinements barriers are maintained,
- level 2 : the reactor compartment is taken out of the submarine, size reduced to a minimum, and air-tightness of the compartment maximised, simplifying reactor monitoring.
- level 3 : all radioactive components have beenremoved – radiation monitoring and inspection is no longer required.

Four decommissioning options were considered :

- **Strategy #1** : **Final disposal of the Reactor Compartments as a whole**
  - Option #1 : in situ, in the sarcophagi, avoiding Reactor Compartments removal operations.
  - Option #2 : in a near surface disposal facility located on the Paldiski site.
- **Strategy #2:** **Full dismantling of the RCs**
  - Option #1 : Minimising cutting works in order to lower men exposure.
  - Option #2 : Decontaminating and cutting components into small pieces in order to sort wastes, in view to reduce the resulting waste volume (using or not melting devices).

These decommissioning options are detailed in the second intermediate report reference <2>. A short description of the main stages of each option is given below.

1.5.1 First decommissioning strategy option 1 : Final disposal of the RCs as a whole in situ, in the sarcophagi, avoiding RC removal operations

The works to be carried out in order to transform the sarcophagi into small final disposal sites, in accordance with Estonian regulations and IAEA recommendations are summarised below :

- Soil, geological, geotectonic and hydrological surveys on the possibility of permanent in-situ disposal
- Fitting out RCs with Fire extinguishing systems
- Fitting out RCs and sarcophagi with an air conditioning system in order to avoid confinement barriers 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,
  - works to reinforce sarcophagi superstructure,
  - waterproofing sarcophagi and improving containment capabilities,
- 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.

Regarding the problem related with the presence of small radioactive sources in RC#1, we think that as each source contains little radioactivity of its own, it could be possible to extract them after 50 years if necessary, when the radiation dose rate in the reactor compartments is lower.

1.5.2 First decommissioning strategy option 2 : Final disposal of the RCs as a whole in a near surface disposal facility located on the Paldiski site

This decommissioning option rests on the following steps :

- Carrying out preliminary works in the RCs
- Erecting a new building on Paldiski site.
- Building a special heavy-duty route between the sarcophagi and the new building.
- Transferring the RCs as a whole from the sarcophagi to the new building.

The preliminary works to be carried out in the RCs consists in filling the primary circuit with concrete, in order to stabilise waste and to provide against corrosion risks, and to extract as much as possible of the combustible materials (like rags, plastic, wood etc ..)

The new disposal building would have to be built as an extension (North side) of the building #301/302, to reduce the length of the heavy-duty way as much as possible. This building must be designed for both reactor compartments disposal, according to IAEA requirements for the design of near surface repository for low and intermediate level waste.

After erecting a new disposal building, a heavy-duty route is to be constructed between the sarcophagi and the new building. This route could be designed for railway or wheel transfer.

Transferring the RCs in their entirety would be a difficult operation (each one weights about 1000 tons), this has been studied by VNIPIET institute. This work could be performed using hydraulic jacks to lift the reactor compartment and to lean it on a slipway trolley introduced in the free space under the reactor compartments. Reactor Compartment #2 would be transferred first to the disposal building. After that, Sarcophagus #2 would be completely dismantled, and the heavy-duty road would be prolonged towards Sarcophagus #1.

The Reactor Compartments transfer as described above is not fully consistent to the radioactive waste transport regulation due to their total enclosed activity, but as the waste packages are transported on tens of meters with no exit of the Paldiski site, we think that this option could be reasonable. This option is the one that was selected by TECHNICATOME to transfer in 1993 the reactor compartment of the first French nuclear submarine called Le Redoutable to the building dedicated to its temporary storage.

The surveillance program of Reactor Compartments and Disposal building should be in force for a minimal period of 300 years.

It appears that waiting fifty years before implementing this first 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 first decommissioning strategy would be implemented as soon as possible.

However, as for option 1, we suggest to postpone the extraction of small radioactive sources after a 50 years storage period if necessary, when the radiation dose rate in the reactor compartments is lower.

1.5.3 <u>Second decommissioning strategy : Full dismantling of the RCs</u>

The framework can be resumed as follows :

- Restoration of standardised storage conditions for the storage period :
  - Improvement of RCs resistance against corrosion.
  - Sarcophagi strengthening and improvement of sarcophagi confinement properties.
  - Improvement of sarcophagi resistance against flood.
  - Implementing the surveillance program.

- During the storage period, the following works should be performed :
  - Building of the Estonian radioactive waste surface storage site.
  - Transfer of the waste already stored in building #301/302 to this storage site.
  - Building of a “packaging workshop” in building #301/302.
  - Upgrading of the 50 tons crane lift of this building.

- Complete dismantling of the RCs into pieces to be transferred to the “packaging workshop” : usable techniques for operations are detailed, and schematic flowcharts of dismantling operations are provided.

- Packaging of the arising radioactive waste. Two different options will be considered for radioactive waste packaging :

  - Option n°1: Making special waste packages minimising cutting works.
    Special waste packages are prepared in the "packaging workshop" in accordance with the storage rules. These packages are made from whole NPU systems like reactor vessel, steam generator vessels, etc , minimising cutting works. The final volume of waste might be high, but the dismantling and packaging operations are simplified and men exposure minimised.

  - Option n°2: 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, recycling by the mean of melting devices, etc. Most of the additional work is done in the "packaging workshop".
    The study of this option considers the use of decontamination to re-categorise waste and melting to further reduce the volume of waste for disposal. Given the current state of information it could be possible to carry out In-Situ decontamination of the reactor coolant circuits to assist with their decommissioning. However this would involve the need to develop safety cases for its use along with the design of significant capital equipment. Lastly there would be the requirement to treat the liquid effluents resulting from the decontamination process used. The use of melting of the resulting waste as a means of achieving free release and or to reduce waste volumes and disposal costs has been discussed. Whether melting is a cost effective approach will depend on many factors, and in particular Estonia should consider a possible agreement with a foreign country operating a melting facility. 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.

- Release of the site after dismantling and decontamination of the sarcophagi.

Regarding total men exposure, waiting until the year 2050 could result in a total men exposure up to ten times lower. This is due to the composition of the gamma radioactivity spectrum. Spectrum repartition shows that Co-60 is the more significant gamma high-energy radionuclide. Its half-life is 5.3 years. In the year 2050, Co-60 activity will have decreased one thousand times, and total gamma dose rates will have decreased up to ten times. Considering this dismantling strategy, that implies heavy dismantling works near gamma radioactive sources, the influence of the storage period is actually very important.

In other respects, we think that it's possible to guarantee the reliability of the confinement barriers for 50 years provided that some complementary safety provisions be implemented (these safety provisions are described in reference <2>, § 6.2). But if it comes to extend the storage period up to 100 years or more, the works to be carried out would be similar to those described as First Strategy – Option 1 (Final disposal of the RC in their sarcophagi – see reference <2>, § 5.2). These works are much heavier and much more expensive. Moreover, the gamma dose rate decrease will be much slower after 50 years, and the influence of the storage period might not be really significant either regarding waste volumes. For these reasons, we recommend that this second decommissioning strategy would be implemented after a storage period of 50 years.

1.5.4 <u>advantages and drawbacks of each decommissioning option</u>

The main advantages and drawbacks of each decommissioning option have been studied and synthesised in the following table :

Decommissioning Strategy	Advantages	Drawbacks
First Decommissioning Strategy Disposal of the RCs as a whole	– Except radioactive sources extraction, the works to be carried out would not imply high men exposure. – The risk of radioactivity release into the environment is reasonably low.	– Waste packages (RCs) are not consistent to IAEA recommendations regarding waste management – Waste packages are not totally immobilized into the final disposal.
Decommissioning Option 1 In situ disposal in the sarcophagi	– This option does not require heavy dismantling works. – As a consequence, the global cost would be quite low. – No radioactive waste transport is required.	
Decommissioning Option 2 On-site near surface disposal at Paldiski	– Reactor compartments transfer to the disposal building could be considered as a radioactive waste transport, but this radioactive waste (the reactor compartments) remains on the Paldiski site.	– This decommissioning option requires heavy works to transfer the RCs into the disposal building. – As a consequence, the global cost would be much higher than for option #1. – The Reactor Compartments transfer is not fully consistent to the radioactive waste transport regulations due to their total enclosed activity, but as the waste packages are transported on tens of meters with no exit of the Paldiski site, this option seems to be reasonable.
Second Decommissioning Strategy Full dismantling of the RCs	– Waste packages are consistent to the IAEA recommendations regarding waste management. – Waste package (parallelepipeds) will be totally immobilised into the final disposal. – Waste packages transport to the disposal site is fully consistent with Estonian regulations and IAEA recommendations regarding radioactive waste transport, <u>except for RC#1 reactor vessel</u> (but RC#1 reactor vessel transport could be reasonably performed, providing eventually some complementary safety measures)	– This decommissioning strategy requires heavy works to dismantle the Reactor compartments. These works imply a very high labour, and a quite high total men exposure. – As a consequence, the global cost would be higher than for first strategy. – The risk of radioactivity release into the environment is reasonably low, but higher than for the first strategy.
Packaging Option 1	– Total men exposure is lower than for packaging option #2	– The resulting waste volume is higher than for packaging option #2
Packaging Option 2	– The resulting waste volume is lower than for packaging option #1	– Total men exposure is higher than for packaging option #1

1.6 TASK 3 : EVALUATION OF DISMANTLING STRATEGIES

The evaluation of these decommissioning strategies will rest on the following steps :
- Estimation of wastes volumes,
- Estimation of decommissioning works cost,
- Estimation of total men exposure resulting of the decommissioning works.

2 WASTE VOLUMES ESTIMATES

2.1 FIRST DECOMMISSIONING STRATEGY

The radioactive waste volume is the whole volume each reactor compartment with its support :

	Overall dimensions (m)	Volume (m3)	Weight (tons)
Reactor Compartment #1	8,1x15,3x8,8	1090	930
Reactor Compartment #2	10,7x8,4x10,9	980	950
TOTAL		2070	1880

In the case of option 2, the dismantling of sarcophagi will also produce 3300 tons of non radioactive concrete waste (2500 tons for Sarcophagus N°1, and 800 tons for sarcophagus N°2). The resulting non-radioactive waste volume is 1600 m3.

2.2 SECOND DECOMMISSIONING STRATEGY

2.2.1 Packaging option 1

The standard containers measurements are 1,2mx1,2mx1,2m. These measurements have been chosen in order to be fully consistent with those of containers being stored in the interim storage.

Special containers measurements are multiples of standard containers measurements, in order to optimise storage into disposal facility.

2.2.1.1 Inventory of radioactive waste to be packed in special containers

The following tables have been drawn up on the basis of the reactor compartments inventories attached in appendix 1.

	Nb	Overall component dimensions (mm)	Components weight (tons)	Special container dimensions (m)	Special containers volume (m3)	Waste package weight (tons)
STAND 346 A						
VM-A reactor vessel	1	2100x2100x 4295	30	2,4x2,4x4,8	27,6	44
Steam generator chambers	8	940x 940x2300	2,7	1,2x1,2x3,6	5,2	9
Pressurizers (x4)	1	620x450x34 50	4,74	1,2x1,2x3,6	5,2	10,5
2 Pressurizers and 2 activity filters	1	620x450x34 50 550x475x17 90	3,47	1,2x1,2x3,6	5,2	10
RC#1 primary circuit room	8	2200x1800x 1800	18	2,4x2,4x2,4	13,8	26
IWS Tank	2	2300x2300x 3200	21	2,4x2,4x3,6	20,8	34
TOTAL	**22**		**245**		**232**	**412,5**

	Nb	Overall component dimensions (mm)	Components weight (tons)	Special container dimensions (m)	Special containers volume (m3)	Waste package weight (tons)
STAND 346 B						
VM-4 reactor vessel	1	2250x2250x 4660	50,4	2,4x2,4x4,8	27,6	62
Steam generator – Primary circuit pump block	5	1550x1136x 4485	14,2	1,2x2,4x4,8	13,8	36
Pressurizer	3	795x795x28 26	2	1,2x1,2x3,6	5,2	10
Primary circuit filter	1	800x800x20 75	2	1,2x1,2x2,4	3,5	7
Primary circuit filter cooler	1	800x800x21 30	2,78	2,4x2,4x2,4	13,8	7,7
IWS Tank	4	3050x2200x 2400	16,5	2,4x2,4x3,6	20,8	32
TOTAL	**15**		**200**		**212**	**415**

2.2.1.2 Inventory of radioactive waste to be packed in standard containers

According to the second intermediate report (reference <2>), about 1000 tons of miscellaneous low contaminated waste (concrete, steel, lead carborite, asbestos, etc) will be produced in the course of the dismantling operations of both reactors.

	Total weight of miscellaneous low radioactive waste (tons)	Nb	Standard container dimensions (m)	Standard containers volume (m3)	Waste package weight (tons)
	1000	300	1,2x1,2x1,2	1,7	62
TOTAL	**1000**	**300**		**510**	**1500**

2.2.1.3 Total waste volume

According to the tables above, the total volume of waste packages to be stored in the final disposal facility is up to 950 m3. The corresponding total weight is 2330 tons.

2.2.2 Packaging option 2

The aim of this packaging option is to minimise the final volume of waste, using techniques like decontamination, compaction, recycling by the mean of melting devices, etc. Most of the additional work is done in the "packaging workshop". The reactor vessel is the single primary circuit component that couldn't be processed in a melting facility : its size, weight and activity are too high to allow its transportation.

Given the current state of information, it could be possible to further reduce the volume of waste for disposal of 20% using in-situ decontamination of the reactor coolant circuits.

According to experience in other European countries, the use of melting of the resulting waste could allow to reduce their volume of 20% to 30% more.

3 COST ESTIMATES

The cost estimates have been drawn up for each decommissioning option from the breakdown of tasks given in appendix 2 and appendix 3.

The organisation of workforce is considered to be as follows :

	Team composition (men.month)									
Team	Project leader	Engineer	Site foreman	Designer	Highly skilled worker	Team foreman	Radioprotection Technician	Qualified worker	Operator / handler	Total payroll
Study team	0,2	2	1	2						5,2
Civil works installation / non active dismantling team	0,1	0,5			4	1		4	4	13,6
Installation and mechanical test team	0,2	1	1	1	4	1	0,2		2	10,4
Dismantling team	0,1	0,25	0,25		1	1	1	1	2	6,6
Handling and logistics team 1	0,1	0,25	0,25			1			3	4,6
Handling and logistics team 2	0,1	0,25	0,25			1			3	4,6
Cutting / packaging workshop team	0,1	0,25	0,25		1	1	1	1	2	6,6
Site total	0,4	1	1		2	4	2	2	10	22,4

As often as possible, the cost estimates have been drawn up having recourse to local workforce, except for the following positions :

- project leader (1),
- engineers (2)
- designers (2)
- radioprotection technicians (2).

This choice does not question local workforce skills. But to ensure safety of such operations, it's necessary to involve highly specialised staff, that could concurrently complete local team training in nuclear technologies.

The rate of western staff within the total payroll is less than 30%. So the average man-month rate remains below EUR 3500.

We saw in the second intermediate report (ref. <2>, § 4.3.2.1) that in accordance with the European transport regulations:

- RC#2 may be transported in a A-type container after the year 2030.
- RC#1 may be transported in a A-type container only after the year 2165.

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 (See the local roads pictures in appendix 5). And there's no suitable infrastructure on the Paldiski site to allow the shipping of the reactor compartments (See the coastline pictures in appendix 5).

The problem is quite similar if we consider the transportation of the waste package containing only the vessel of RC#1or RC#2 (second strategy). The weight of these containers is lower (62 tons and 44 tons), but remains high enough to require heavy works on the road network. Furthermore, as the radioactivity is almost entirely located within the reactor vessel, the necessary decay before transportation is the same for RC#1 vessel waste package as for RC#1 as a whole.

For these reasons, the repository has been assumed to be located on the Paldiski site for each decommissioning strategy quotation. As explained in the second intermediate report (ref. <2>, § 5.2.1), the Pakri Peninsula seems to be a convenient area, but this fact should be confirmed on the basis of a specific survey. Furthermore, from a political angle, this assumption is much more preferable, because it does not result in creating one more radioactive site.

Finally, the quotation for the decommissioning of RC#1 has been drawn up very accurately from the sequences given for each dismantling strategy in the second intermediate report (ref. <2>). The quotation for the decommissioning of RC#2 has been drawn up from the quotation for RC#1, on the basis of the followings ratio :

		K coefficients where RC2 Decommissioning Costing = K x RC1 Decommissioning Costing				
Strategy	Option	Studies	Equipment	New work (installation)	Dismantling work	Dose
First strategy	Option 1	0,5	0,4	1	-	0,5
First strategy	Option 2	0,5	0,2	1	1	0,5
Second strategy	Option 1	0,8	0,2	0,2	1	0,6

3.1 FIRST DECOMMISSIONING STRATEGY

3.1.1 First decommissioning strategy option 1 : Final disposal of the RCs as a whole in situ, in the sarcophagi, avoiding RC removal operations

This quotation has been drawn up taking into account the building of a surface disposal facility, of the same type as Centre de l'Aube in France, made for low and medium level short-lived radioactive waste. This facility is necessary to allow final disposal of the waste that have been temporary stored in the interim storage compartments. Its capacity should be 4000 m3 or so, and it would be fitted out with a 20 tons gantry crane. 4000 m3 is quite high regarding the amount of waste to be disposed of (See Ref. <1> § 8.1), but it's necessary to take into account potential wastes arising from Tamiku and Sillamaë sites. Moreover, reducing the disposal capacity below 4000 m3 wouldn't result in a cost reduction.

This cost estimation has been drawn up considering that the required equipment would be rented as much as possible. The average rental cost of a piece of equipment has been estimated to 18% of its purchase price.

The total cost of this dismantling option is estimated to 5.2 million of EURO for both reactor compartments, including the erection of the disposal site building (EUR 750 000).

The breakdown of tasks and the detailed quotation is given in appendix 2.

3.1.2 First decommissioning strategy option 2 : Final disposal of the RCs as a whole in a near surface disposal facility located on the Paldiski site

The total cost of this dismantling option is estimated to 7.6 million of EURO for both reactor compartments. This amount includes the erection of a 4000 m3 disposal site building fitted out with a 20 tons gantry crane (EUR 750 000), and the construction of a heavy duty railway (100 meters long) from building 301/302 to the disposal site location.

This cost estimation has been drawn up considering that the required equipment would be rented as much as possible. The average rental cost of a piece of equipment has been estimated to 18% of its purchase price.

The breakdown of tasks and the detailed quotation is given in appendix 2.

3.2 SECOND DECOMMISSIONING STRATEGY

3.2.1 First waste packaging option : Making special waste packages minimising cutting works.

The total cost of this dismantling strategy is estimated to 14.1 million of EURO for both reactor compartments. This amount includes the erection of a 4000 m3 disposal site building fitted out with a 70 tons gantry crane (1 million of EURO), and the cost of sarcophagi reinforcements and improvements that are necessary to ensure the safety of the 50 years storage period before carrying out dismantling works (the cost of these works is estimated to EUR 700 000 for both sarcophagi).

The total cost of radioactive waste packaging is estimated to EUR 2.5 million, including waste containers purchasing.

The breakdown of tasks and the detailed quotation is given in appendix 3.

3.2.2 Second waste packaging option : Minimising the volume of definitive wastes, using in situ decontamination and melting devices

According to the analysis carried out by BNFL, the estimated costs of the design and construction of an In-Situ decontamination plant based upon the current BNFL designs is of the order of EUR 13 to EUR 16 Million.

As said in section 2.2.2, 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. The total cost of radioactive waste packaging would be reduced in the same ratio, from EUR 2.5 million to EUR 2 million. 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.

As said in section 2.2.2, 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 depends on many factors and a specific economic evaluation should 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.

4 TOTAL DOSE

The total men exposure has been calculated for each decommissioning strategy from the current dose rates given by VNIPIET (See first intermediate report reference <1>).

4.1 FIRST DECOMMISSIONING STRATEGY

4.1.1 First decommissioning strategy option 1 : Final disposal of the RCs as a whole in situ, in the sarcophagi, avoiding RC removal operations

The total men exposure is 330 men.mSv. This dose is mainly due to the works necessary to extract miscellaneous radioactive wastes that have been stored into the reactors compartments, including radioactive sources.

4.1.2 First decommissioning strategy option 2 : Final disposal of the RCs as a whole in a near surface disposal facility located on the Paldiski site

The total men exposure is 560 men.mSv. As in the case of the first decommissioning option, this dose is mainly due to the works necessary to extract miscellaneous radioactive waste from the reactors compartments, but also to the works necessary to lift the reactor compartments, that implies the presence of workers under the reactor vessel, in the area where dose rates are higher.

4.2 SECOND DECOMMISSIONING STRATEGY

4.2.1 First waste packaging option : Making special waste packages minimising cutting works.

The total men exposure is much higher in the case of this decommissioning strategy : 1780 men.mSv. Indeed, the work necessary to carry out the complete dismantling of the reactor compartments implies the presence of workers close to highly activated components as reactor vessel or shielding tank structure. However, if the dismantling works are carried out after a 50 years storage period, the total men exposure could be reduced to 600 or 700 men.mSv.

4.2.2 Second waste packaging option : Minimising the volume of definitive wastes, using in situ decontamination and melting devices

This waste packaging option implies to carry out the same dismantling works as the first one, but further waste treatment requires more handling. For this reason the total men exposure is perceptibly higher, and can be estimated to 2000 men.mSv considering the current dose rates. If dismantling works and waste packaging works are carried out after a 50 years storage period, the total men exposure could be reduced to 700 or 800 men.mSv.

5 CONCLUSION : RECCOMMENDATION OF THE BEST DECOMMISSIONING OPTION

The tables below summarises the data given above :

	Total MO (k hours)	Total MO (M EURO)	Total Cost of Equipment (M EURO)	Duration of decommissioning works (years)	Total Dose (h.mSv)	Dose per man per year (mSv/man/year)	TOTAL (M EURO)	TOTAL (M EEK)
FIRST DECOMMISSIONING STRATEGY : FINAL DISPOSAL OF THE REACTOR COMPARTMENTS AS A WHOLE								
Option 1 : Final disposal of the Reactor compartments in their sarcophagi	117	2,60	2,60	3,5	328	6,4	5,20	81,5
Option 2 : Final disposal of the Reactor Compartments as a whole in a repository located on the Paldiski site.	214	3,96	3,64	5,5	555	5,2	7,60	119
SECOND DECOMMISSIONING STRATEGY : COMPLETE DISMANTLING OF THE REACTOR COMPARTMENTS								
Waste packaging option 1 : Making a few big definitive packages	328	7,26	6,84	6,6	1781	9,6	14,10	221

Note :
Waste Packaging option 2 : See § 3.2.2.

The main advantages and drawbacks of each decommissioning option has been summarised in the table of § 1.5.4.

As a conclusion, the different strategies drawn up appear to be deeply different. The result of their implementation would be quite different, and the estimated cost of the most expensive strategy (second strategy) is nearly three times as much the cost of the less expensive option (first strategy, option 1).

From a strictly technical angle, we can say that these three strategies would result in an acceptable situation regarding its radiological impact, as 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 strategies. So the most cost effective strategy to reach a safe situation seems to be the first one.

But as shown by the table of § 1.5.4, which summarises the main advantages and drawbacks of each option, 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 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.

For these reasons, we recommend the full dismantling of the Paldiski reactor compartments, after a storage period of 50 years. The dismantling works should be implemented in accordance with the strategy drawn up in the course of task 2 of this study (See Reference <2>, Chapter 6). The cost of sarcophagi reinforcements and improvements that are necessary to ensure the safety of the 50 years storage period before carrying out dismantling works has been estimated to EUR 700 000 (EEK 36 million) for both sarcophagi. These works should be implemented as soon as possible.

After that, a founding plan should be drawn up in order to carry out the full dismantling of the reactor compartments after the 50 years storage period. If unfortunately this choice appears to be financially unrealistic for Estonia, the final disposal of the reactor compartments in situ, in the sarcophagi, should be implemented.

6 APPENDIX 1 : MAIN ACTVATED COMPONENTS LIST

7 APPENDIX 2 : COST ESTIMATION AND DOSE EVALUATION WORKSHEETS – FIRST STRATEGY

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6 APPENDIX 1 : MAIN ACTIVATED COMPONENTS LIST

UNIT 346 A (RC# 1)

Equipment component ID	System ID	Room No	Description	V m³	D mm	H mm	F m²	t mm	Material	Remaining water, l	water contamination MBq / kg	Remarks	Surface, m²	Material volume, m³	Weight, kg	Asbestos volume, m³	Contamination	Contaminated Surfaces	Contaminated Weight, tons	Dose Rate, uGy/h	Spécific activity Bq/kg			Total activity Bq		
																				1989	1999	2050	2100	1999	2050	2100
	Unit 1- Primary system																									
		2	VM-A Reactor (with internal parts and control rods)		2100	4295			Carbon steel 48TS + 1Cr18Ni9Ti	70	2,2				30000									3,58E+14	6,80E+13	4,64E+13
PG-14t		9	Steam Generator and attached pipelines (SGC #3,4)		940	2300			1Cr18Ni9Ti - Carbon steel - Ti	25	2,2	boron carbide			5400									2,00E+06	2,12E+04	1,48E+04
PG-14t		9	Steam Generator and attached pipelines (SGC #2,5)		940	2300			1Cr18Ni9Ti - Carbon steel - Ti	25	2,2	boron carbide			5400									6200	67,7	47
PG-14t		9	Steam Generator and attached pipelines (SGC #1,6)		940	2300			1Cr18Ni9Ti - Carbon steel - Ti	25	2,2	boron carbide			5400									20	0,2	0,1
PG-14t		9	Steam Generator and attached pipelines (SGC #7,8)		940	2300			1Cr18Ni9Ti - Carbon steel - Ti	25	2,2	boron carbide			5400									0,1	0	0
MCP-146		10 12	Main coolant pump of the primary circuit		1250	2170			1Cr18Ni9Ti						4600											
ACP-147P		10 12	Auxiliary primary circuit pump		850	1870			1Cr18Ni9Ti						1800											
Sb-13/Sb-14		6	Pressurizer 1		620	3450			1Cr18Ni9Ti - 20CrMo Steel	17	2,2				7110									2330	2,4	1,7
Sb-13/Sb-14		6	Pressurizer 2		620	3450			1Cr18Ni9Ti - 20CrMo Steel	17	2,2				7110									2330	2,4	1,7
Sb-13/Sb-14		6	Pressurizer 3		620	3450			1Cr18Ni9Ti - 20CrMo Steel	17	2,2				7110									2330	2,4	1,7
Sb-13/Sb-14		6	Pressurizer 4		620	3450			1Cr18Ni9Ti - 20CrMo Steel	17	2,2				7110									2330	2,4	1,7
Sb-13/Sb-14		6	Pressurizer 5		620	3450			1Cr18Ni9Ti - 20CrMo Steel	17	2,2				7110									2330	2,4	1,7
Sb-13/Sb-14		6	Pressurizer 6		620	3450			1Cr18Ni9Ti - 20CrMo Steel	17	2,2				7110									2330	2,4	1,7
AF		2	Activity Filter N°1		475	1790			1Cr18Ni9Ti - MNZhMTs 30-1-1	7	2,2				565											
AF		2	Activity Filter N°2		475	1790			1Cr18Ni9Ti - MNZhMTs 30-1-1	7	2,2				565											
MCP-601		9	Cooler MCP-601		460	1100			1Cr18Ni9Ti						300											
CMCP-146M		12	Cooler CMCP-146M		346	1200			1Cr18Ni9Ti - MNZh 5-1						114											
CACP-147M		12	Cooler CACP-147M		240	1200			1Cr18Ni9Ti - MNZh 5-1						52											
		2	Primary circuit pipelines attached to the reactor, in reactor enclosure		108			11,0	1Cr18Ni9Ti	20	2,2										707000	141000	100000			
		2 6	Primary circuit "cold" pipelines located in corridors		140			15,0	1Cr18Ni9Ti	20	2,2															
		12	Primary circuit pipelines in CPS enclosure to/from MCP (beneath shielding)		180			17,0	1Cr18Ni9Ti	20	2,2										212	42	30			
		12	Primary circuit pipelines in CPS enclosure to/from ACP (beneath shielding)		108			11,0	1Cr18Ni9Ti	20	2,2										212	42	30			
		12	Small primary circuit pipelines in CPS enclosure (beneath shielding)		15			2,5	1Cr18Ni9Ti																	
		12	Small primary circuit pipelines in CPS enclosure (beneath shielding)		28			4,0	1Cr18Ni9Ti																	
		9	Primary circuit pipelines in SG enclosure (left board)		140			15,0	1Cr18Ni9Ti	20											283	56	40			
	Unit 1- Other components																									
	(activated)																									
		2	IWS Tank						1Cr18Ni9Ti	70	<4 Bq/kg															
		9	Secondary circuit pipelines in SG enclosure (left board)						1Cr18Ni9Ti	1000	<4 Bq/kg										283	56	40			
		10	Third circuit pipelines in CPS enclosure (beneath shielding)						1Cr18Ni9Ti																	
		9 2	Walls of SG enclosure opposite to the reactor						Steel 20K												17,8	0,2	0,13			
		10 12	Floors of the corridors and CPS enclosures						Steel 20K												2,23	0,02	0,01			
		1	Strong vessel of RC below the reactor, along RC axis						Steel AK-25												126000	10500	7400			
		1	Strong vessel of RC below IWS tank, without reactor						Steel AK-25												2000	166	117			
		8	Concrete						Concrete												68000	3500	259			
	Unit 1- Other components																									
	(non activated)																									
2P-2		10	Pump 2P-2		660	1600			1Cr18Ni9Ti						525											
TSN21		10	Pump TSN21		570	906			1Cr18Ni9Ti						292											
TSN23		10	Pump TSN23		510	1003			1Cr18Ni9Ti						280											
VP2-1-0-0		10	Heat exchanger VP2-1-0-0		600	1510			1Cr18Ni9Ti						450											
Pr50-2		10	Current converter Pr50-2		1634	2140			carbon steel + copper						9035											

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UNIT 346 B (RC# 2)

Equipment component ID	System ID	Room No	Description	V m³	D mm	L mm	l mm	H mm	F m²	t mm	Material	Remaining water, l	water contamination MBq/kg	Remarks	Surface, m²	Material volume, m³	Weight, kg	Contamination	Dose Rate, uGy/h	Dose Rate, uGy/h	Dose Rate, uGy/h	Spécific activity Bq/kg			Total activity Bq		
																			1994	2050	2100	1999	2050	2100	1999	2050	2100
	Unit 2- Primary system																										
			VM-4 Reactor (with internal parts and control rods)		2250			4660			Heat-resistant steal	400	1				50400										
			Steam Generator - Primary circuit pump block N° 1			1550	1136	4485			Stainless steal	450	0				14200										
			Steam Generator - Primary circuit pump block N° 2			1550	1136	4485			Stainless steal	450	0				14200										
			Steam Generator - Primary circuit pump block N° 3			1550	1136	4485			Stainless steal	450	0				14200										
			Steam Generator - Primary circuit pump block N° 4			1550	1136	4485			Stainless steal	450	0				14200										
			Steam Generator - Primary circuit pump block N° 5			1550	1136	4485			Stainless steal	450	0				14200										
			Shutdown primary circuit cooling pump		566			1135			Stainless steal						750										
			Pressurizer 1		795			2826			Heat-resistant steal	50	1				2000										
			Pressurizer 2		795			2826			Heat-resistant steal	50	1				2000										
			Pressurizer 3		795			2826			Heat-resistant steal	50	1				2000										
			Primary coolant Filter		800			2075			Stainless steal	50	1				1980										
			Primary coolant filter cooler		800			2130			Heat-resistant steal						2780										
			Primary system valve 1		250			1710			Stainless steal						91										
			Primary system valve 2		250			1710			Stainless steal						91										
			Primary system valve 3		250			1710			Stainless steal						91										
			Primary system valve 4		250			1710			Stainless steal						91										
			Primary system valve 5		250			1710			Stainless steal						91										
			Primary system valve 6		250			1710			Stainless steal						91										
			Primary system valve 7		250			1710			Stainless steal						91										
			Primary system valve 8		250			1710			Stainless steal						91										
	Unit 2- Other components (activated)																										
			Shielding Tank body and caissons			2565	4860	6140			Stainless steal	35	<4 Bq/kg														
			Steam shut-off valves (Number : 10)			280	872	1480			Stainless steal						357										
			Feed water valves (Number : 10)			475	1450	1850			Stainless steal						40										
			Floors of the corridors and CPS enclosures								Carbon steal																
			Strong vessel of RC below the reactor, along RC axis								Carbon steal																
			Strong vessel of RC below shielding tank, without reactor								Carbon steal																
			Concrete steal biological shielding blocks (Number : 30+D1)			475	1450	1850			Concrete + lead + carbon steal			lined by stainless steal			1270										
	Unit 2- Other components (non activated)																										