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STUDSVIK/N-14/281

Study on future decommissioning of nuclear facilities in Norway – Task 3 Waste management

Per Lidar
Tommi Huutoniemi

Studsvik Report

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STUDSVIK NUCLEAR AB

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2014-06-30

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Abstract

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Studsvik’s part of the mission focuses on Task 1 Waste inventory and Task 3 Radwaste Management (this report), and for this, Studsvik is using a risk based radwaste management concept utilizing knowledge and experience from international and national decommissioning and major modernization projects. Totally three options for radwaste management have been studied, including direct disposal (waste conditioning for Himdalen, called option a), treatment for recycling off-site (option b), and, treatment for recycling on-site using waste plant partly built up for decommissioning (option c). Calculations (drum equivalents of waste and associated costs) are made for Halden and Kjeller for all three options. It should be noted that both treatment for recycling options contains waste streams for direct disposal.

The concept of treatment for recycling off-site and on-site is based on a risk and radioactivity activity-based categorization and handling of all materials and waste from decommissioning. The final state of a large amount of material and waste after treatment is expected to be clearance (from regulatory control), which means that materials can be recycled and the radioactive waste that must be disposed can be greatly restricted.

For several of the waste streams, an estimated 95% by weight of the material being considered for treatment off-site could be released for unrestricted use. Treatment for recycling on-site is expected to generate somewhat larger amount of waste for final disposal and at a higher cost. Direct disposal gives the highest volumes of waste for final disposal. Both lower and higher estimates for waste to be disposed of at Himdalen compared with the IFE estimated volumes are presented in this report.

Reviewed by		Approved by	
	2014-09-29		2014-09-29
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Table of contents

Appendices

A Waste management facilities on- and off-site

B Management of waste streams from decommissioning

C Task 3-model for waste management

D Compilation of decommissioning waste data

1 Introduction

This report was prepared as a part of the concept choice study (KVU) for future decommissioning of the nuclear facilities in Norway. The KVU is conducted by DNV GL with Studsvik, Westinghouse and Samfunns- og Næringslivsforskning (SNF) commissioned by the Ministry of Industry and the Ministry of Fisheries in Norway (NFD).

The KVU will provide a recommendation on the most optimal socio economic level for decommissioning when the facilities in Halden and Kjeller are shut down in the future. In addition the KVU will provide a recommendation on decommissioning strategies and provide input to the decision about how to allocate the total costs.

The Institute for Energy Technology (IFE) has a license for the operation of Norway's two research reactors at Kjeller and in Halden. It is not decided when or if any decommissioning of the nuclear facilities is to take place.

During previous applications for operating licenses IFE has established decommissioning plans that vary somewhat from this study both in regards to scope – what buildings and areas are included - and the way the level of decommissioning is defined.

1.1 Background

The existing nuclear facilities in Kjeller and Halden i.e., two research reactors, a number of laboratories, fuel storage facilities and waste treatment facilities are to a certain degree similar to the facilities at the Studsvik site in Sweden and other nuclear research facilities developed in Europe in the 1950’s and 1960’s.

Common for all nuclear installations are that they sooner or later have to be decommissioned. The existing nuclear power plants as well as the facilities on research centres are in many cases, due to political decisions, of economic reasons or due to aging, to be decommissioned in the coming decade.

Due to this fact, the two companies Studsvik and Westinghouse have formed a joint venture named ndcon. The two companies have different backgrounds but are highly experienced in nuclear decommissioning but in different perspectives. Both companies are license holders for nuclear facilities according to the Swedish Nuclear Act.

1.2 Purpose

The purpose of this report is to assess radwaste management (RWM) options for waste arising from the future decommissioning of nuclear facilities at Halden and Kjeller. The assessment is based on the Task1 Waste Inventory.

1.3 Method

The RWM method in Task 3 is based on information gathered from various sources (references, meetings, documents, other facilities) combined with previous Studsvik experience.

The RWM is focusing on waste volumes and the cost associated with waste treatment and disposal, and will cover the whole decommissioning phase from shutdown of normal operation to hand-over of the sites after the chosen end-state.

1.4 Scope, delimitations and assumptions

The Task 3 report covers the scope and waste inventory at Halden and Kjeller as described in the Task 1-report [Huutoniemi, 2014]. The same delimitations and assumptions as for Task 1 apply, i.e., assessment has been performed based on existing information.

2 Background

IFE has licenses for operation of the research reactors at Kjeller and Halden. IFE has in December 2010 and in June 2012 to the Competent Authority sent in updated decommissioning plans for the IFE nuclear facilities, including financing of these plans.

It is not decided when decommissioning of the IFE nuclear facilities will take place.

The Norwegian state sees a need to explain and justify the level of decommissioning that will be chosen for the decommissioning of the nuclear facilities in Norway. The justification shall take into consideration the consequences for the environment and the communities at the locations, the security risks and the cost level for a specific choice of decommissioning level, as well as the national permissions and relevant international regulations.

The government intends, based on recommendations, to make a decision about a conceptual solution for the level of decommissioning for the future decommissioning of the nuclear facilities at Kjeller and in Halden. The foundation for the decision will be a conceptual choice investigation (konseptvalgutredning, KVU), which is the scope of supply for the work which this report is part of.

The KVU shall be quality assured externally through a quality assurance process (KS1) as determined by the Financial department frame agreement of March 4, 2011.

DNV GL has been commissioned by the Norwegian Ministry of Trade, Industry and Fisheries regarding “A concept selection study on future decommissioning of nuclear facilities in Norway.” Studsvik and Westinghouse have been engaged to assist DNV GL with the execution of the mandate according to below. Overall, Studsvik and Westinghouse deliver four tasks.

This report focuses on using data from Task 1 (Waste Inventory) as the input to Task 3 (Radwaste Management). Three options for radwaste management (RWM) should be evaluated within the assignment:

a. Direct disposal, which essentially involves direct transport to Himdalen.

b. Treatment aiming for recycling in a specialised facility off-site.

c. Treatment aiming for recycling on-site which means waste treatment locally at Halden and Kjeller, respectively.

2.1 Present situation in Norway

Several decommissioning plans (DP) have over the years been delivered from IFE to the competent authority, Strålevernet. The latest updates are from 2012 and include cost estimations and waste volumes to be sent for disposal. Some material is also assumed to be subject for clearance from regulatory requirement, after treatment locally at Halden or Kjeller.

2.2 International experience and recommendations

IAEA provides international experience and recommendations in the field of decommissioning, e.g., [IAEA, 1999c], which also IFE refers to in its DPs. Generally, a decommissioning project need to choose a strategy, an end-state, and an RWM option, see Table 2-1.

Table 2-1
Commonly used decommissioning strategies, end-states and RWM options.

Decommissioning strategy	End-state*	RWM option
1. Immediate	A. Un-restricted usage	a. Direct disposal
2. Deferred	B. Industrial	b. Recycling off-site
3. Entombment	C. Other nuclear activity	c. Recycling on-site

* The end-state for the facilities, i.e., what the facilities can be used for after decommissioning.

3 Conclusions and recommendations

Three RWM options have been assessed for a future decommissioning of the nuclear facilities at Halden and Kjeller. The options are:

a. Direct disposal
b. Treatment aiming for recycling at a facility off-site
c. Treatment aiming for recycling at a facility on-site

The options have been evaluated based on the waste inventory compiled in Task 1. The waste volume to be disposed at the repository at Himdalen and the associated cost with the waste treatment and conditioning of the waste have been calculated for the options. The results have been used as input to Task 4 Cost estimates.

The Task 3-model for the RWM includes judgments based on a risk based concept for waste handling, developed from the Studsvik experience of RWM in similar projects. It should be noted that the options called “treatment for recycling” will contain waste streams that will be disposed without treatment as well as waste that will go through clearance procedures on site. The options indicates the main focus.

The results of the Task 3-model used on the Task 1 inventory shows that:

- Treatment for recycling off-site (option b) is calculated to generate the lowest amount of waste for final disposal, and at the lowest cost.
- Treatment for recycling on-site (option c) is expected to generate a larger amount of waste for final disposal and at a higher cost.
- Direct disposal (option a) gives the highest volumes of waste for final disposal.
- Both lower and higher estimates for waste to be disposed at Himdalen compared with the IFE estimated volumes are presented in this report.

The estimated range of disposal volumes and costs for the three options are:

Volumes: 2 709 (option b) −4 344 (option a) drum equivalents[1]

Costs: MNOK 183 (option b) −268 (option c)

It is recommended that the IFE waste inventory is updated with more precise information about the radiological status of the facilities and its system. A more precise estimation for the different RWM options can then be given.

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[1] Disposal volume for waste used by IFE for calculating required repository volume.

4 Task 3 – Waste Management

The RWM for the upcoming decommissioning waste from Halden and Kjeller is assessed in this chapter. It is assumed that the:

- Decommissioning strategy is immediate dismantling.
- End-state is unrestricted use.

Three RWM options as described will be evaluated. Task 3 needs input and information from other tasks for the assessment.

4.1 Task 1 Waste inventory

The waste inventory (radiological and volume/mass) from Task 1 in the most important information as input to Task 3.

4.2 Task 2 Dismantling techniques

Task 2 is providing information about applicable techniques for the dismantling and how the waste are provided for further handling from the dismantling team, which is of importance for the Task 3 assessment.

4.3 Regulatory requirements in Norway

In order to evaluate the proper radioactive waste management methods to utilize in the decommissioning programs, a review of the available requirements has been made. The purpose has been to find requirements that have a significant impact on the possibility to choose strategy and methods.

4.3.1 Laws and regulations

The regulations which have an effect on radioactive waste management are:

- Regulations on radioactive contamination and waste (Forskrift om radioaktiv forurensning og avfall)
- Regulation on waste (Avfallsforskriften)
- Regulation on nuclear materials etc. (Forskrift om nukleært materiale m.m.)
- Requirements for annual reporting for operations managing radioactive waste (Retningslinjer for årlig rapportering for virksomheter som håndterer radioaktivt avfall.)

These laws and regulations provide the framework for waste management in Norway. As such, they do not go into detail in many areas which specifically impact the chosen strategy.

The regulations on radioactive contamination and waste do, however, contain regulatory limits regarding what waste that is to be considered as radioactive waste, as well as limits regarding what waste must be disposed of as such, no regulations or laws with a significant impact on the choice of waste management strategy has been found.

No regulations regarding packaging specific documentation, such as regarding waste type descriptions, has been found.

4.3.2 Facility specific regulations

The main facility that has an impact on the waste management strategy is the disposal site, KLDRA-Himdalen.

Based on [SAR], [kapacitetsvurdering], the following requirements or limitations have been found

- The packaging concept used by the repository operator is based on variations of three basic packages; 210-litre drums, concrete boxes and steel boxes. The specific package used is mainly based on dose rate requirements and may, if needed, contain various amounts of radiation protection. The steel boxes are available with varying outer dimensions.
- The package dose rate limit is generally 10 mSv/h (in the facility, not for transport to the facility). This is based on the fact that during transport the waste package itself serves as the transport package.
- There are no limitations on specific nuclides, but a general requirement that the repository may not cause doses to critical group in excess of 1 µSv/y from the most probable scenarios 300 or 500 years post-closure.
- Disposed waste should contain less than 400 Bq/g alpha nuclides for the whole repository, and less than 4 000 Bq/g alpha nuclides for individual packages.

4.3.3 Evaluation of regulations

This section discusses the regulations and how these are taken into consideration in the assessment.

A comparison of the rules has been made to the regulations given by the Swedish authorities, a country with which Norway may reasonably be assumed to cooperate. This is based on an assessment that there are less regulations on the waste management area than in many other jurisdictions, which indicate that there may be a need for further development. The fact that Sweden has nuclear power plants has certainly affected the regulations, and made is easier to motivate more detailed regulations for e.g., waste and its handling, treatment, and disposal.

General waste management regulation
Based on this comparison it is clear that the Norwegian system is less strictly regulated than that of Sweden, for example in the areas of waste documentation. The Swedish system has regulations on waste type description documents, strict registering of all waste in detailed waste management database systems, etc. This indicates a larger degree of flexibility in the Norwegian system, which is advantageous from a hands-on-perspective, but put more requirements on traceability and records as a wide range of waste with different origin can be loaded in a container.

There are no specific regulations with significant impact on factors such as mixing of waste composition, packaging of waste etc.

Clearance of material
Both countries have classifications regarding what is considered as radioactive waste. In Sweden, all waste from nuclear activities is considered to be nuclear waste until proven otherwise. The Norwegian system does not have specific documentation regarding the process for clearance of material from this categorization. In the report it is assumed that a system similar to the one in operation in Sweden will be in place by the time the decommissioning is initiated.

Based on the Swedish system, the process of clearance puts a large responsibility on the operator to demonstrate that clearance can be achieved by performing a detailed risk assessment that is used in conjunction with measurements. Experience has shown that if detailed knowledge e.g. regarding the history of the material and its risk for contamination is lacking, the clearance process can be resource intensive with impacts on overall waste management logistics (e.g. through need of long clearance measurement times and larger volumes that need to go through a full clearance process). This means that for planning of a decommissioning project care should be taken to correctly estimate the amount of waste that may be subject for clearance.

In addition, the Norwegian legislation allows for some material below a certain threshold, but still considered as radioactive, to be managed without requiring disposal. It is, however, not specified how this fraction of waste should be handled. For this reason, the current assessment has assumed that all waste that does not undergo the clearance procedure is to be disposed.

IFE has in [D063] proposed to use the IAEA recommendations RS-G-1.7 [IAEA, 2004] for materials.

Clearance of buildings
IFE has in [D063] proposed to use the EC recommendations RP 113 [EC, 2000] for buildings. Also the Swedish regulation is based on RP 113.

Clearance of land
Norway has no regulation on clearance of land, but it is foreseen that regulations will be needed in order for the preparation of future decommission and waste management plans.

Clearance of sites
Norway has no regulation on clearance of sites (whole facilities including land), but the regulations for clearance of material and buildings are used where applicable.

Dose rates
KLDRA-Himdalen does currently only manage and dispose waste with dose rates below 10 mSv/h. While this requirement will be satisfied for the majority of waste, there is a fraction of waste where this requirement may be difficult to.

The current assessment does not take this dose rate limit into consideration since it is likely that some packages either will have to be exempted from this requirement, or there will be a need for additional as of yet undetermined new types of waste packages.

Nuclide contents
Due to the indirect nuclide content requirement regarding the total dose received by a member of the critical group, the compliance with this requirement is difficult to verify without detailed information on the nuclide contents for the critical nuclides of all waste.

IFE, which is responsible for decommissioning as well as operation of the repository, assumes in its decommissioning studies that all decommissioning wastes should be possible to dispose of in KLDRA-Himdalen. For this reason, the same assumption has been used here.

4.4 International recommendations

Under the terms of Article III of its Statute, the International Atomic Energy Agency (IAEA) is authorized to establish standards of safety for protection against ionizing radiation and to provide for the application of these standards to peaceful nuclear activities. The regulatory related publications by means of which the IAEA establishes safety standards and measures are issued in the IAEA Safety Standards Series. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (that is, of relevance in two or more of the four areas), and the categories within it are Safety Fundamentals, Safety Requirements and Safety Guides. The IAEA’s safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities.

The IAEA has outlined policies and strategies for RWM [IAEA, 1999d], but has also issued other safety related publications [IAEA, 1995, 1996a, 1996b, 1999a, 1999b, 1999c], which are applicable in a general sense for the Task 3 assessment. The IAEA stresses that a waste management plan, part of the decommissioning plan, should consider the different categories of waste produced during decommissioning and aim at the safe management of such wastes [IAEA, 1999d]. The predisposal management is described in [IAEA, 2009].

4.5 Conditions for the waste management

To be able to make a good estimate of the waste management it is of large importance that relatively detailed information about amount of waste of the different categories and its properties are available. For the work for this report Studsvik used mainly data from the Task 1 report, and data from existing decommissioning plans [D058, D059, D061-D065)], have been used as comparison.

Although there is are a lot of information about the facilities, it has been shown that in some cases important and relevant information is not available to be able to make a good estimate of the properties of waste and contamination levels. Where the necessary information is not available assessments have been made, see the Task 1 report [Huutoniemi, 2014].

4.5.1 Existing infrastructure at IFE

The existing infra-structure at IFE has been evaluated for the different RWM options, and judgments have been made about possible gaps between existing infra-structure and the needed infrastructure for the different options. The need for equipment and facilities will also depend on the option chosen. Initial judgments about the existing infrastructure vs. the needs during the decommissioning are included in the Task 3 assessment.

4.5.2 Waste streams

The waste that will be generated during the decommissioning process are described in the Task 1 report [Huutoniemi, 2014]. Based upon that the following division into waste streams was done:

- Process Components
    - Including reactor vessel and internals
- Pipes
- Ventilation systems
- Concrete
    - Including biological shield
- Structural steel
- Reinforcement
- Combustible waste
- Liquid waste
- Cables and chutes
- Other waste

Available data for liquid waste and other waste (i.e., soil) are very limited and are not part of the Task 3 output to Task 4. It needs to be included in future assessments.

4.5.3 Volumes and radiological inventory

Volumes and radiological inventory (total activity and nuclide specific) of the waste is to certain extent described in a number of references such as SAR, decommissioning studies, component databases. The inventory is supplemented in the Task 1 report with Studsvik's estimates where deemed needed.

The decommissioning waste is categorized in the Task 1 report [Huutoniemi, 2014] based upon the following:

- Intermediate level waste (”ILW”)
    - > 1 MBq/kg
- Low level waste category H (LH)
    - 100 kBq/kg to 1 MBq/kg
- Low level waste category M (LM)
    - 20 kBq/kg to 100 kBq/kg
- Low level waste category L (LL)
    - 1 kBq/kg to 20 kBq/kg
- Material potentially subject to clearance (LLW)
    - < 1 kBq/kg
- Material with low risk for radiological contamination
- Material with extremely low risk for contamination (NC)

From [Huutoniemi, 2014], the following waste inventory is the basis for the Task 3 evaluation, see Tables 4-1−4-3:

Table 4-1
Waste distribution over activity class, Halden (tonne) [Huutoniemi, 2014].

Category	Unknown	NC	VLL	LL	LM	LH	H	Total	Total excl. NC
Components	26.7	14.2	35.6	62.1	0	0	144.7	283	269
Pipes	0	1.5	0.4	1.7	0	0	6.8	10	9
Cabling. chutes	0	0.4	30.3	0	0	0	0	31	30
Ventilation	0	0.1	0	30.4	0	0	0	31	30
Structural steel	0	0.3	20.5	0	0	0	0	21	21
Concrete	0	24 462	160	0	380	0	0	25 002	540
Reinforcement	0	525	0	0	0	8	0	533	8
Incinerable	0	0	50	0	0	0	0	50	50
Total Halden	**27**	**25 003**	**297**	**94**	**380**	**8**	**152**	**25 960**	**957**

Table 4-2
Waste distribution over activity class, Kjeller (tonne) [Huutoniemi, 2014].

Category	Unknown	NC	VLL	LL	LM	LH	H	Total	Total excl. NC
Components – Electrical	0	11	0	0	0	0	0	11	0
Components – Electric cabinets	0	11	0	0	0	0	0	11	0
Components – Overhead cranes	0	0.3	43	0	0	0	0	43	43
Components – Actuators and valves	0	2.7	5.6	8.3	0	0	0	17	14
Components – Heat exchangers	0	1.3	3.2	5.5	0	0	0	10	8.7
Components – Misc.	0	8.5	70	6.8	30	9	10	134	126
Components – Pumps	0	0.6	1.1	1.7	0	0	0	3.4	2.8
Components – Tanks and cisterns	0	3.0	7.3	13	0	4.5	1.5	29	26
Components – Internal components	0	0	0	0	0	0	2.5	2.5	2.5
Components – Reactor tank	0	0	0	0	0	0	0.6	0.6	0.6
Components – Thermal shield	0	0	0	0	0	0	9.4	9.4	9.4
Components – Insulation	0	0	6.1	0	0	0	0	6.1	6.1
Pipes	0	1.0	2.5	5.2	0	0	0	8.7	7.7
Cables, ladders, chutes	0	0.6	21	0.2	0	0	0	22	21
Structural steel	0	0	15	0	0	0	0	15	15
Concrete/leca/tegel	0	11 114	82	0	0	10	223	11 429	315
Reinforcement	0	1 234	0	0	0	5.1	0	1 239	5.1
Components – Metal	0	100	0.38	5.4	0	45	0	151	51
Ventilation	0	1.7	8.51	30	0	1	4.9	46	4
Components – Handling equipment	0	0	1	0	0	2.8	0	3.8	3.8
Components – Heating and sanitation – pipes	0	12	0	0	0	0	0	12	0
Components – Heating and sanitation – components	0	2.2	0	0	0	0	0	2.2	0
Incinerable	0	0	36	0	0	0	0	36	36
NALFA	0	0	8	0	0	0	0	8	8
Total Kjeller	**0**	**12 503**	**310**	**46**	**30**	**77**	**252**	**13 249**	**745**

Table 4-3
Waste distribution over activity class, Halden and Kjeller (tonne) [Huutoniemi, 2014].

Facilities	Unknown	NC	VLL	LL	LM	LH	H	Total	Total excl. NC
Halden	27	25 003	297	94	380	8	152	25 960	957
Kjeller	0	12 503	310	76	30	78	252	13 249	745
Total IFE	**27**	**37 506**	**6077**	**170**	**410**	**86**	**403**	**39 209**	**1 703**

4.5.4 Necessary information for efficient waste handling

For proper planning of the decommissioning waste management, a lot of information will be needed. Through the characterisation of the facilities obtained prior to the start of the dismantling, an adequate estimate of the inventory of materials and radionuclides will be achieved. This information will together with process knowledge and an analysis of the options available form the basis for the planning of waste management.

Relevant information regarding the inventory of radionuclides and hazardous substances, material compositions and other relevant properties should be part of a database to manage information in the demolition waste.

Traceability is important for all waste to be handled and disposed. Package ID, measurement results for radioactivity, nuclide vectors and measured weights should be stored in a database. Pictures of the content prior to conditioning should be taken and stored in the database, if possible.

Prior to transport and subsequent treatment, the necessary information is collected (dose rate, activity content (nuclide vector), weights, material type, deviations from agreements or drawings, etc.).

4.5.5 Logistics

Smoothly functioning logistics is essential through each of the decommissioning processes including the waste management process. There are logistic needs from several aspects as:

- To secure safe movement of materials
- Free up space in the plant.
- Optimize the use of resources.
- Minimize the need of project specific buffer storages for untreated waste.

Some important parameters to create smoothly functioning logistics:

- Experience, competence and understanding.
- Structure and planning, doing things in the right order requires proper planning.
- Efficient (waste amount per time) and robust processes.
- Close cooperation including short information and decision-making paths between stakeholders.
- Well-defined and pre-determined waste streams including its management.
- Periodic analyses with respect to bottle necks.

The proposed overall logistics (for all options of waste treatment) are shown in Figures 4-1−4-3.

4.5.6 Requirements for temporary storages

The needs for short term buffer storages look slightly different depending on whether the outbound transport will be done in campaigns or as soon as a set of containers are filled up. More frequent shipments lead to a smoother process.

Outdoor storage of nuclear material and nuclear waste is normally only allowed at approved fenced locations provided with a hard surface. Potential spread of contamination is not accepted why the waste should be containerized, wrapped or placed in drums or boxes.

If, where and how a package shall be stored outside depends on the content of radioactive and nuclear materials. Generally, nuclear waste is limited by the activity content and nuclear materials are limited by the amount of nuclear material. In cases where the material will be stored as both nuclear waste and nuclear material, it is the rating that provides maximum security that will be limit setting.

4.5.7 Conditions for transportation

The conditions for transportation are important for several aspects. The larger, heavy or more radioactive a shipment unit is the more complex. In general, it can be summarised that transport of most material from a nuclear site decommissioning project should not be problematic or costly. They use to be managed as general ADR shipment by truck.

For large and heavy components or objects with a high radioactivity content special arrangement may be required. Large components are typically recognized within the nuclear industry as such that will not fit into an ordinary 20 foot IP-2 container.

4.5.8 Transport legislation

The Norwegian legislation for transport of material classified as dangerous goods is built on:

- The law on transport of dangerous goods.
- The regulation on transport of dangerous goods.
- Regulations issued by the competent authority.

For transport of dangerous goods by:

- Sea applies the IMDG-code.
- Road applies the ADR-code.
- Air applies the RID-code.

For the road transports of decommissioning waste from IFE, it is foreseen that a few UN-numbers will be used, such as:

- UN 2910, RADIOACTIVE MATERIAL, EXCEPT PACKAGE - LIMITED QUANTITY OF MATERIAL
- UN 3321 RADIOACTIVE MATERIAL, LOW SPECIFIC ACTIVITY (LSA-II), non fissile or exception fissile
- UN 3322 RADIOACTIVE MATERIAL, LOW SPECIFIC ACTIVITY (LSA-III), non fissile or exception fissile
- UN 2913 RADIOACTIVE MATERIAL, surface contaminated objects (SCO-I or SCO-II), non-fissile or exception fissile.

4.6 Waste management strategy

The waste management strategy should outline the aims and objectives with the waste management process including how the waste should be handled, if clearance of contaminated or potentially contaminated waste should be taken into account, whether external resources should be used or if the entire project will be handled mainly with in-house resources and capabilities.

A waste management plan is essential for a decommissioning project at an early stage as it forms a platform for licensing, investments and the development of the more detailed waste management plans.

IAEA states [IAEA, 2009]
3.17. The operator is responsible for establishing and implementing the overall strategy for the management of the waste that is generated, and for providing the required financial securities, taking into account interdependences among all steps in waste management, the available options and the national radioactive waste management policy.

In general three different options exist for the waste management:

- On-site waste management of all the waste focusing on packaging for direct disposal. This option is called option a in this report.
- Waste potentially possible for clearance without treatment will be handled on site. Material that requires treatment to be subject to clearance will be sent off-site for treatment. Residues from the treatment and material not subject to clearance after treatment will be returned. Material not found potentially possible or worth the cost to clear will be packed for disposal locally. This option is called option b in this report.
- On-site waste management focusing on treatment for clearance to the extent possible. Packaging for disposal for the reaming material and the residues generating during the treatment operations. This option is called option c in this report.

4.6.1 Waste management concept

Based on own experiences and lessons learned from international decommissioning projects where Studsvik has played a central role in the management of waste (i.e., waste processor), Studsvik suggests a concept for optimized waste management from decommissioning of nuclear facilities.

The concept is based on the principles that have been developed by the Swedish nuclear industry under the project Industry Practices Clearance [SKB, 2011a].

The concept applies to RWM options a, b and c, and involves that the demolition and the breakdown in waste streams is done by a risk-based assessment, where each category is handled separately. The concept are summarized in Figures 4-1−4-3. Depending on the material's condition, optimized treatment is selected. The final state of a large amount of waste will be free release, which means that valuable materials can be recycled and disposal as radioactive waste can be avoided.

Facility status and starting points for assessment of waste and necessary actions for the demolition is obtained by the radiological survey. During the demolition, as waste streams and material grades are classified, the waste is packed in agreed packages.

For the waste category of risk assessment Low Risk, a targeted and random spot check is performed in Halden, resp. Kjeller, to confirm the risk assessment process. Normally, no radioactivity should be detected in the sample check, and clearance can then be made for the waste. If activity is detected on the other hand, the waste, according to the principles identified are re-classified into Risk. In addition, the cause of the erroneous risk assessment is analysed.

4.6.2 Concept purpose

The purpose of the developed concept is to create favourable conditions for environmentally sound and cost-effective waste management during decommissioning of nuclear facilities. A basic requirement in the development of the concept has been that all waste handling should be in terms of radiation protection and ALARA principle should be followed, i.e., the dose rate exposure to staff, public and the environment during a normal decommissioning project should be as low as reasonable achievable.

4.6.3 Potential waste routes

The following potential waste routes have been identified:

- Transport of conditioned waste packages from the nuclear facilities or a central waste management facility to Himdalen (or any other at that time available disposal site).
- Transport to a central Norwegian waste management facility for treatment. The conditioned material, i.e. all material not subject to clearance will either be returned to the owner or directly sent to the disposal site. The latter is preferred.
- Transport to an international waste treatment facility such as Studsvik in Sweden, Siempelkamp in Germany or Centraco in France. The international treatment facilities require a guarantee that any material, not cleared and recycled, will have to be taken back in either form. It is preferred that the material is conditioned for final disposal before return.

4.6.4 Radwaste management option a, direct disposal

When applying the concept for RWM option a, the flowchart for the waste logistics is shown in Figure 4-1. No specific waste treatment is included in this option, and the actions taken are focused on clever sampling and measurements on site, and conditioning of waste for disposal at Himdalen. Appendix A outlines the needed waste management at Halden and Kjeller.

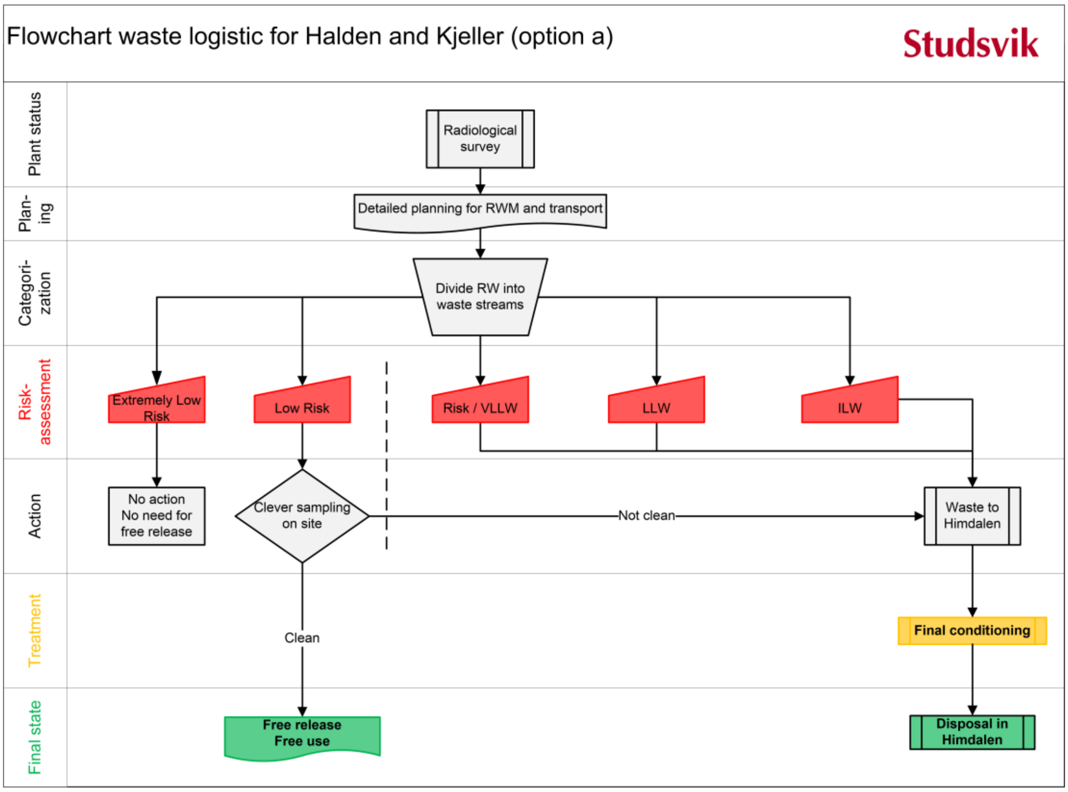

Figure 4-1
Flowchart waste logistics for decommissioning of Halden and Kjeller, option a.

4.6.5 Radwaste management option b, recycling off-site

When applying the concept for RWM option b, the flowchart for the waste logistics is shown in Figure 4-2. Most of waste that needs treatment is packed and shipped off-site for treatment. On-site work is focused on clever sampling, measurements for clearance, and conditional of waste for disposal at Himdalen. Appendix A outlines the needed waste management at Halden and Kjeller, as well as off-site at a separate supplier.

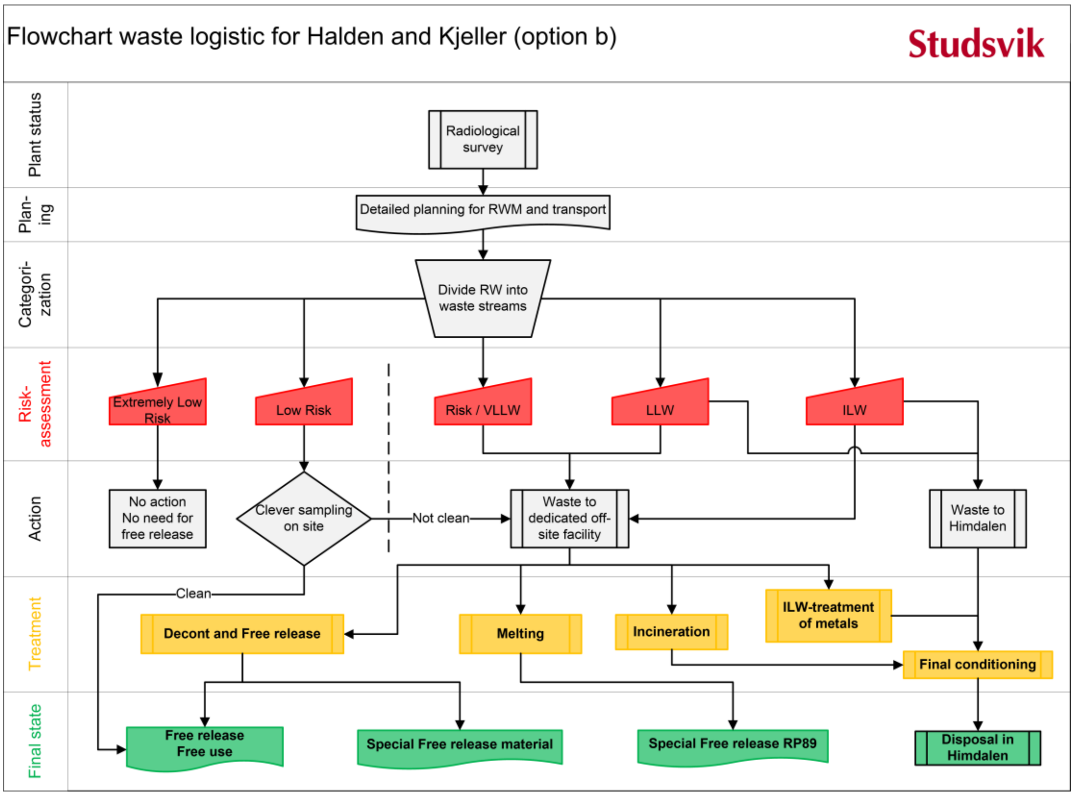

Figure 4-2
Flowchart waste logistics for decommissioning of Halden and Kjeller, option b.

Up to 20 years of decay storage of the produced metal ingots prior to free release is assumed and considered in the estimates. This is a proven concept.

4.6.6 Radwaste management option c, recycling onsite

When applying the concept for RWM option c, the flowchart for the waste logistics is shown in Figure 4-3. The sampling, measurements for clearance, and conditioning of waste for disposal at Himdalen is the same as for options a and b, but some waste treatment will also be performed locally on-site with the goal of clearance of material for unrestricted use. Appendix A outlines the needed waste management at Halden and Kjeller.

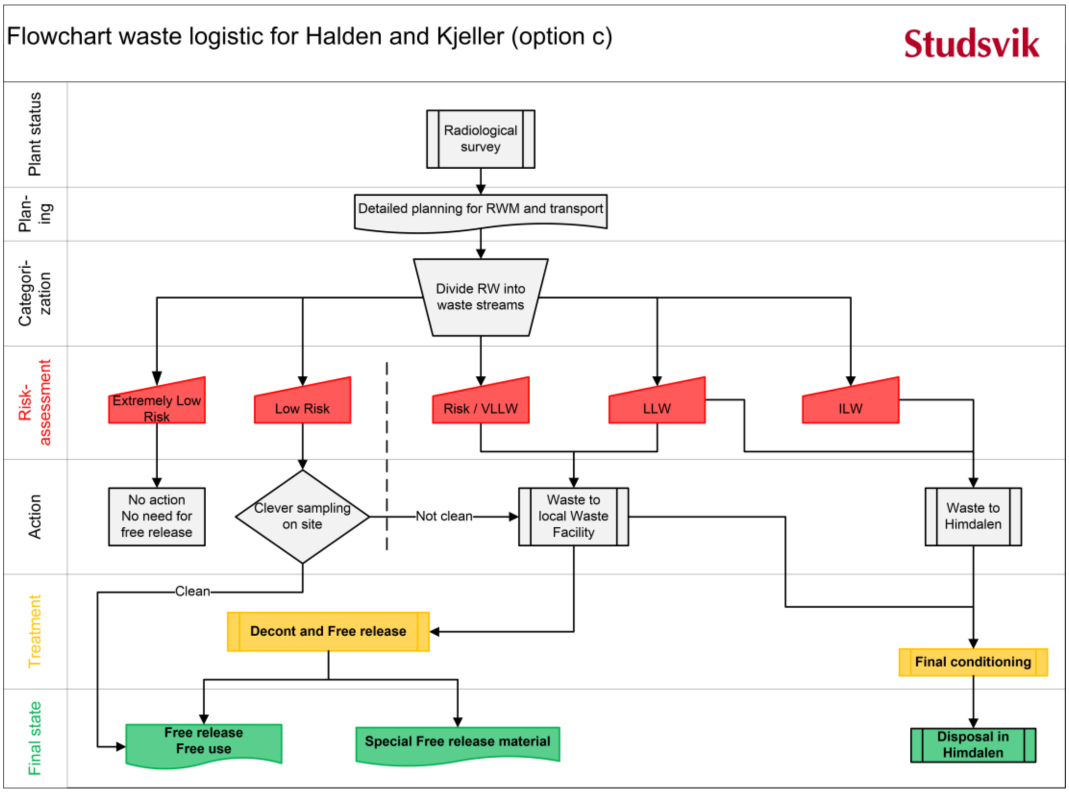

Figure 4-3
Flowchart waste logistics for decommissioning of Halden and Kjeller, option c.

4.7 Pre-decommissioning waste management activities

Among the pre-decommissioning waste management activities with largest impact on the overall project cost (i.e., normally the same as project execution time), the following can be mentioned.

Activities that can be prepared during the operational phase:

- Historical surveys in records as well as interviews.
- Updated and relevant waste information in a structured database.
- Good knowledge of the plant status by a thorough radiological survey.
- Detailed planning for RWM and its transportation.
- Waste management plan approved by competent authority.
- All necessary licenses approved by competent authority.

4.8 Waste containers

On the international market there are a numerous different types of containers for transport, storage and/or disposal or radioactive waste. It must be noted that many of the existing container and disposal concepts have been tailor-made for a specific repository. The general reflection is that commercially available packages manufactured in large series are preferred of cost reasons conditioned to that they fulfil the WAC for the repository.

4.8.1 Waste containers in the Norwegian system

Types available:
The 2012 decommissioning plan [D063] states that IFE is using the following waste containers:

- Drums or steel cages of carbon steel (SS 1142).
- Steel cages or drums in stainless steel (AISI 316).
- Drums in stainless steel (AISI 304).
- Concrete boxes (for disposal in the storage part of KLDRA).

Steel boxes are used for larger objects and contaminated material with low dose rate. The drums have net volume for waste in the range 60 – 210 L, while the steel cages has approx. 3000 L net volume for waste. The concrete boxes have net volume for waste in the range 128 – 360 L.

Maximum waste package weight is 5 tonne, which is the lifting limit at KLDRA.

Some tanks will be disposed as is and filled with other waste (may require license from the competent authority).

Potential improvements:
Drums are not very efficient package type regarding required volume for disposal. Besides this, is can be costly to dismantle waste is small parts in order to fit the drums. A potential improvement, to save cost for dismantling and space at KLDRA, is to avoid drums and use square shaped boxes instead.

New packages:
New package types for the disposal of waste may be needed, if it becomes important to save space for the disposed waste, or for other reasons.

4.8.2 International outlook

Waste containers have been used for a long time in the systems in Sweden, Germany and the UK, since the three countries have had nuclear research facilities and power plants for more than 50 years.

Sweden
There are several standardised waste containers in the Swedish system for waste disposal in the SKB disposal SFR at Forsmark. A formal process of licensing new waste containers exists, and development in new waste containers are on-going for several of the nuclear licence holders.

There is also a detailed licensing procedure for exactly what waste types each container type is allowed to contain, including allowed properties for the waste itself. The licensing procedure is linked to the SAR for the repository site.

Germany
A similar situation with standardised waste container types exist in Germany, and since no final disposal sites for the more contaminated LLW or ILW exists, the waste is normally stored at the local decommissioning site for a longer time.

There are disposal sites in Germany for the waste categories with lowest levels of radioactivity, and they have standard waste container types that they are allowed to take care of.

The UK
The largest disposal site in the UK for LLW is the Low Level Waste Repository, LLWR, at Drigg. They receive waste in standardised container types (e.g., half-height 20 foot ISO containers), that have been conditioned by the waste producer following agreed procedures.

4.9 Waste handling

The management of the waste streams from the decommissioning will differ between the RWM options, and a short overview of the waste management steps involved is given in Appendix B.

4.9.1 Waste categories

The waste arising during decommissioning can be categorised in a number of different ways.
A few examples:

- Type of material as concrete, metals, combustible waste etc.
- Risk for contamination/radioactivity level.
- The waste can/should also be categorised based upon content of long lived nuclides. Short lived nuclides are nuclides with a half-life <31 years.
- Based upon location.
- Size (for example large components and “containerized material”).

We have in this study primarily categorised the material as per the concept for decommissioning waste management (see Appendices A –C).

This means to divide in the following:

- Extremely low risk for contamination (=no risk, no actions needed).
- Low risk for contamination (certain random checks to be performed but otherwise no action).
- Risk for contamination (most likely subject to clearance but can be contaminated above threshold value).
- VLLW (so low levels of radioactivity that it can be subject to general or conditional clearance after treatment or sent directly to a qualified landfill repository).
- LLW (may be subject to clearance after treatment, < 2 mSv/h in contact dose rate or activity <1 MBq/kg).
- ILW (contact dose rate > 2 mSv/h or activity >1 MBq/kg).

In this waste categorisation (the categories Risk for Contamination and higher), waste considered as long lived should be kept apart from the short lived waste. The reason for this is that the disposal options can be or are different (since the safety case is different). Waste Acceptance Criteria for disposal should be consulted.

Secondly the waste is categorised based on material. This categorisation should be as precise as practically possible unless the material is subject for direct clearance.

Thirdly it can for practical reasons be wise to categorise the material depending on size and shape.

To the extent practically possible the waste should be categorised prior to the dismantling process.

4.9.2 Segregation

In order to achieve the wanted efficient waste flow through the facility, it is important to segregate firstly on the risk for radiologically contaminated waste from the waste that have low and extremely low risk for radiologically contamination, and secondly, different categories of waste.

If the segregation is poorly performed or performed without traceability, it will lead to increased costs for waste handling, measurements, transports, documentation and, disposal.

4.9.3 Waste treatment

The treatment of the decommissioning waste depends to a large extent on the selected strategy and the disposal and clearance options available. Another factor is the availability of and services within potential waste treatment facilities. As an example; it is very efficient to burn combustible low level waste but the investments in such a facility is large and by then not realistic to invest in for a country with a small nuclear program.

Appendix B gives a short overview about the proposed possible options with regards to waste treatment. The overview is given per waste stream and for all the RWM options.

4.9.4 Clearance of material

Background
Radioactive or potentially radioactive material can be exempted from regulatory control in three ways exclusion, exemption and clearance. In the decommissioning process only the terminology clearance apply.

Clearance can be defined as *“the removal of radioactive materials or radioactive objects within authorized practices from any further regulatory control by the regulatory body”*. Furthermore, the new BSS [EC, 2014] state that “clearance levels shall take account of the exemption criteria and shall not be higher than the exemption levels or defined by the regulatory body". A footnote indicates that "Clearance of bulk amounts of materials with activity concentrations lower than the guidance exemption levels may require further consideration by the regulatory body".

Current situation
Norway has no regulation on clearance of land. IFE has in [D063] proposed to use the IAEA recommendations RS-G-1.7 [IAEA, 2004] for materials and EC recommendations RP 113 [EC, 2000] for buildings.

Recommendation
Norway should consider to develop a national regulation for clearance preferably based on the international recommendations by IAEA and/or EC. It is also recommended that a national guidance is developed similar to what exist in for example Sweden or the UK.

With a well-developed clearance process a large percentage of the entire amount of waste and material can be cleared for reuse, recycling or conventional disposal.

4.9.5 Management of combustible waste

Background
The normal practice is either to compact organic waste before or during conditioning for disposal, or to incinerate it for volume reduction and to transfer it to an inert ash.

Organic waste is normally considered as a problem (due to potential gas formation) in a disposal perspective why incineration is preferred in many countries even though the cost is higher.

Current situation
Norway do presently not use incineration as a waste treatment method. It may be related to a combination of small yearly volumes and that the waste has to be sent abroad for treatment.

Recommendation
Norway should evaluate if organic waste from decommissioning could be a problem in the repository Himdalen.

4.9.6 Decontamination

Background
Decontamination by blasting is commonly used for metals from decommissioning projects, and is effectively used for more or less all components in the primary circuit of a reactor, as well as for other facilities with surface contaminated metallic waste. Also for the IFE decommissioning, decontamination by blasting is considered as effective in order to reduce levels on radioactivity that allows free-release.

Current situation
Blasting to the extent foreseen in this report for the decommissioning projects is not present today at Halden or Kjeller.

Recommendation
Make efficient use of blasting in the functional specification for the needed RWM facilities utilized for the decommissioning project.

4.9.7 Melting of metals for recycling or volume reduction

Background
The normal practice is to melt metals for recycling or volume reduction, assuming that the contamination levels and other parameters is suitable for treatment by melting.

Current situation
Norway do presently not use melting as a waste treatment method. It may be related to a combination of small yearly volumes and that the waste has to be sent abroad for treatment.

Recommendation
Norway should evaluate if melting for volume reduction from decommissioning could be an option for the repository Himdalen.

4.9.8 Radioactivity determination

Background
During a decommissioning project, large waste volumes needs to monitored on-site for radioactivity determination. Robust, efficient, and redundant monitoring lines is normally required to allow the required flow of material and waste away from the site.

Current situation
The existing monitoring capabilities will not be enough for the decommissioning project.

Recommendation
The functional requirements for new monitoring lines needs to be included in the overall planning for the project specific RWM facilities. This is independent of what RWM option that will be used.

Equipment failures could lead to many weeks of stand still time since the market is dominated by a few larger vendors, and the consequence for the decommissioning project needs to be evaluated.

4.9.9 Conditioning for disposal

Background
IFE is conditioning operational waste in agreed waste container types. The corresponding is foreseen for the decommissioning project.

Current situation
Since the volume of waste to be conditioned for disposal at Himdalen will increase by order of magnitude during the decommissioning project, the installed capacity at IFE for conditioning of waste will most likely not be enough. An enhanced capacity will be needed, also because of more waste types to be handled during the decommissioning.

Recommendation
Include the functional requirement for waste conditioning in the planning for the project specific RWM facilities.

4.10 Storage and disposal

Background
During a decommissioning project, some buffer storage on-site of waste containers prior to disposal is difficult to avoid. Depending on the local conditions (buffer storage, transport possibilities and disposal capabilities) it may vary greatly how much buffer storage capacity will be needed on-site.

Current situation
IFE is using buffer storage for some waste streams prior to disposal. Even though the waste volume needed for buffer storage will increase a lot during the decommissioning, both Halden and Kjeller may have limited space to accommodate largely increased need for buffer storage prior to disposal.

Recommendation
The need for buffer storage prior to disposal can largely be reduced by the use of efficient transport concepts, and pre-approved waste routes as described in the waste management plan.

4.10.1 Overview of the repository situation

Background
The geological repository Himdalen exists and is in operation. All decommissioning waste from IFE not subject to clearance is planned for disposal at Himdalen.

Current situation
The projected waste volume from the decommission project is estimated to exceed the remaining free capacity at Himdalen [D063, IFE, 2012].

Recommendation
Evaluate the possible volume and cost saving that can be achieved in the decommissioning project by use of recycling instead of extending the disposal space available at Himdalen.

4.10.2 Waste acceptance criteria for disposal

Background
Waste acceptance criteria for storage and disposal, together with potential improvements for the existing waste packages, and waste package specifications in normally part of the national waste management program. For countries with planned or ongoing decommissioning, the criteria and specifications may need modification to fully incorporate all waste streams specifically generated from decommissioning activities.

Current situation
In the Norwegian system, acceptance criteria exists most likely for some existing packages for operating waste. It is not clear if these packages can be accepted for decommissioning waste.

Recommendation
IFE, the Himdalen repository operator and the competent authority needs to extend and if needed adjust the existing system to also cover decommissioning waste.

4.11 Task 3-model for waste management

A Task 3-model for RWM has been developed, see Appendix C. In short, Table C-1 shows the input to the model, the judgments made, and the output from the model. The Task 3-model is using Task 1 inventory data, and delivering output as waste volumes for disposal and its associated cost to Task 4. See further in Section 4.13.

4.12 Cost

There is a variation in the cost of treatment depending on the type, degree of contamination and shape of the waste. This report has assumed that it is equally costly to manage waste (per tonne) locally in Halden and Kjeller, compared with an off-site facility. It has also been suggested (in the Task 3-model) that it is more difficult to achieve clearance for various waste streams in option c (recycling on-site) compared with option b (recycling off-site).

The cost of treatment for three of the four proposed treatment lines described in Appendix A is calculable and can be described as follows:

- The combustion process is well-defined, waste form known and virtually identical to the process used for operational waste.
- The melting process has the greatest variation when there are large differences in treatment conditions for different items. Cost is affected by the material needs to be decomposed, decontaminated, or otherwise pre-processed prior to melting.
- The Decontamination and Free-release Facility also has a wide range in terms of material-specific processing conditions. Some materials may, after an initial assessment be passed on to activity control while others require extensive disassembly and decontamination before it makes sense to do an activity control.

The conditioning cost for ILW will most likely be much higher per tonne compared with the waste in lower categories, since the requirement for remote handling and shielding complicates the flow of material while escalating the requirements for the handling facility and the associated transports.

To use the concept of waste treatment, investments will be required. This applies regardless of whether the option a, b or c is selected. These can be financed in different ways but will in some way affect the decommissioning project cost. In addition to the actual treatment is added cost of transportation of packages, disposal container handling, transport and technical and administrative management.

A reasonable assumption might be that the average treatment cost (customer price) for the material and the waste treated at an off-site facility is about kNOK/m^3 25–30. Transportation cost is not included in the numbers.

4.13 Output from Task 3

The waste volumes to be disposed at Himdalen together with its associated costs for the three RWM options are output to Task 4, see Section 4.13.

4.13.1 Output to Task 4

Detailed results for each facility at Halden and Kjeller is shown in Appendix D, these results were sent to Task 4.

4.13.2 Output to main report

Task 3 contributes to the main report with input to socio economic analysis:

- Discussion about possible RWM options.
- Description on generated waste from Halden and Kjeller
- Description of investments for the different RWM options

The results from Task 3 will be needed for the socio economic analysis.

4.14 Results of applied RWM concept

The Task 3-model for RWM as described in Appendix C has been applied using input values as described in Tables 4-1−4-4, and [Huutoniemi, 2014].

The results are shown for Halden resp. Kjeller independently, and for the three RWM options a (direct disposal), b (recycling off-site), and c (recycling on-site). A comparison with IFE decommissioning plans is also included.

Table 4-4
Data used for the Task 3-model for RWM.

Category	
Package type	Boxes (concrete or steel)
Packaging efficiency NC-LL+unknown (m^3/ton)	1
Packaging efficiency LM-H (m^3/ton)	1
Volume/package NC-LL+unknown (m^3)	2
Volume/package NC-LL+unknown (m^3)	2
Cost onsite treatment and conditioning (kNOK/ton)	30
Cost offsite treatment and conditioning (kNOK/ton)	30*
Cost transport (NOK/(ton km))	2
Cost disposal (kNOK/fatekv)	20
Cost package NC-LL & unknown (kNOK/package)	8
Cost package LM-H (kNOK/package)	32
Investment cost, direct disposal (MNOK)	20
Investment cost, offsite treatment (MNOK)	10
Investment cost, onsite treatment (MNOK)	40
Onsite conditioning cost, direct disposal (kNOK/ton)	21
Onsite conditioning cost, offsite treatment (kNOK/ton)	21
Onsite conditioning cost, onsite treatment (kNOK/ton)	21
Decont. and dismantling of WF, direct disposal (kNOK)	2 477***
Decont. and dismantling of WF, offsite treatment (kNOK)	2 328***
Decont. and dismantling of WF, onsite treatment (kNOK)	3 096***
Transport distance from Halden resp. Kjeller to Himdalen (km)	100
Transport distance from Halden resp. Kjeller to off-site facility (km)	500
Transport distance from off-site facility to Himdalen (km)**	500

* Incineration cost is about kNOK/ton 100.
** Studsvik is used as example for off-site treatment.
*** Estimated costs for Kjeller, corresponding numbers for Halden are given in Table 4-5.

4.14.1 Halden

Table 4-5 shows the results for all facilities to be decommissioned at Halden. Results for individual facilities are shown in Appendix D. The table shows that RWM option b is calculated to produce the lowest number of drum equivalents (DE) to the lowest overall cost. RWM option a produces the highest number of DE but RWM option c is calculated to have the highest cost.

Table 4-5
Results for Halden using the Task 3-model for RWM.

Category/RWM option	**a**	**b**	**c**
Packaged volume for disposal NC-LL+unknown (m^3)	439	95	359
Packaged volume for disposal LM-LH (m^3)	471	471	471
Total number of drum equivalents	4 344	2 709	3 966
Cost investment (MNOK)	20	10	40
Cost transport (kNOK)	191	577	177
Cost treatment and/or conditioning (kNOK)	20 101	27 120	22 772
Cost packages (kNOK)	9 175	8 071	8 931
Cost disposal (kNOK)	86 880	54 180	79 320
Decont. and dismantling of WF (kNOK)	2 477	1 238	4 954
Total cost (MNOK)	**139**	**101**	**156**

4.14.2 Kjeller

Table 4-6 shows the results for all facilities to be decommissioned at Kjeller. Results for individual facilities are shown in Appendix D. The table shows that RWM option b is calculated to produce the lowest number of DE to the lowest overall cost. RWM option a produces the highest number of DE but the calculated cost is about the same for RWM options a and c.

Table 4-6
Results for Kjeller using the Task 3-model for RWM.

Category/RWM option	**a**	**b**	**c**
Packaged volume for disposal NC-LL+unknown (m^3)	407	55	324
Number of packages LM-H	165	157	165
Total number of drum equivalents	3 471	1 726	3 074
Cost investment (MNOK)	18	17	23
Cost transport (kNOK)	149	553	134
Cost treatment and/or conditioning (kNOK)	15 649	22 472	18 442
Cost packages (kNOK)	6 827	5 422	6 558
Cost disposal (kNOK)	69 420	34 520	61 480
Decont. and dismantling of WF (kNOK)	2 477	2 328	3 096
Total Cost (MNOK)	**113**	**82**	**112**

4.14.3 Total IFE

Table 4-7 shows the results for all facilities to be decommissioned at Halden and Kjeller. The table shows that RWM option b is calculated to produce the lowest number of DE to the lowest overall cost. RWM option a produces the highest number of DE but the calculated cost is slightly lower compared with RWM option c.

Table 4-7
Results for IFE for the Task 3-model for RWM.

Category/RWM option	**a**	**b**	**b**
Packaged volume for disposal NC-LL+unknown (m^3)	846	150	683
Packaged volume for disposal LM-LH (m^3)	788	773	788
Total number of drum equivalents	7 815	4 435	7 040
Cost investment (MNOK)	38	27	63
Cost transport (kNOK)	340	1 130	311
Cost treatment and/or conditioning (kNOK)	35 750	49 592	41 214
Cost packages (kNOK)	16 002	13 493	15 489
Cost disposal (kNOK)	156 300	88 700	140 800
Decont. and dismantling of WF (kNOK)	4 954	3 566	8 050
Total cost (MNOK)	**252**	**183**	**268**

4.14.4 Comparison with IFE decommissioning plans

Comparison with the IFE decommissioning plans (DP) [D058, D059, D061-D065] can be made to a certain extent. Since the DPs are not divided as in the Task 3-model, the cost breakdown is not possible to compare. However, the total number of DE to be sent to Himdalen can be compared, see Table 4-8. From this table it can be seen that the estimates from this Task 3-model is both lower and higher compared with the IFE DPs, which makes sense taking into account the use of slightly different input parameters for certain waste streams (such as concrete and incinerable). Data for the individual facilities is shown in Table 4-9.

Table 4-8
Comparison of results from the Task 3-model for RWM and the IFE overall decommission plan (incl. concrete volume re-calculated as DE).

Source	**Total number of DE**
Task 3-model, RWM option a	7 815
Task 3-model, RWM option b	4 435
Task 3-model, RWM option c	7 040
Total IFE [D063]	**4 860***

* 5 206 if using [D058, D059, D061, D062, D064, and D065].

Table 4-9
Comparison of results from the Task 3-model for RWM and the IFE individual decommission plans (incl. concrete volume re-calculated as DE).

Facility [Ref. see below]	**Total number of DE**			
	IFE DP	**Opt. a**	**Opt. b**	**Opt. c**
HBWR [D065]	3007*	4 344	2 709	3 966
Brenselinstrumentverksted [D058]	0	0	0	0
JEEP II [D061]	870**	1 856	926	1 648
Brenselaboratorier [D059]	1 049^{+}	1 117	726	1 038
Met Lab I [D062]	0	2	2	2
Radavfall [D064]	280^{++}	496	72	386
TOTAL	5 206^{+++}	7 815	4 435	7 040

*: 2 769 DE in [D063]. **: 504 DE in [D063].
$^{+}$: 1 350 in [D063]. $^{++}$: 238 DE in [D063].
$^{+++}$: 4 860 DE in [D063].

The comparison shows that:

- Studsvik's compilation does not deviate significantly towards IFE’s for items that are comparable considering the uncertainties that exist. However, there are differences that should be explored.
- Some waste streams could not be identified in the IFE DPs which makes the comparison difficult.
- Studsvik has more waste mass in the compilation compared with IFE, and is judging the possibility to free-release waste for clearance somewhat differently compared with IFE.
- It may be more relevant to compare the different RWM options in this report with each other, rather than comparing the numbers with the IFE DP numbers, because of the mentioned differences.

By the time decommissioning starts, it is anticipated in this report that the requirements from Strålevernet may be different compared with today’s situation, and based on historical facts new requirements will normally not be less strict. This may influence RWM option c and its degree of clearance possible to reach.

4.15 Discussion

For a decommissioning project, there are essentially two main options for the material or waste, which is or may be radiologically contaminated.

- Packaging, activity determination, followed by disposal.
- Treatment for clearance alternatively volume reduction in order to minimize the amount of materials and waste that must be disposed of as radioactive waste.

Historically, direct disposal has been prevalent for both conventional waste and radioactive waste. Since the late 1990s, both the society (in Norway and elsewhere) realized that the deposition track is not sustainable from multiple perspectives. This insight has been reflected in legislation, for example the Environmental Code in Sweden, involving ionizing radiation and thus apply in parallel with the Nuclear Activities Act and the Radiation Protection Act, and in the National Waste Plan, which excludes radioactive waste.

In the UK, the Waste hierarchy (prevent – reuse – recycle – energy recover – dispose) has been implemented in the nuclear industry, saying that recycling of waste is a more preferred option than disposal.

4.15.1 Impact on disposal volumes

A strategy built on waste treatment and recycling can result in a major impact on the total disposal volume. The assessment in this report estimates that the disposal volumes can be reduced by 43% or 3 380 DE by using optimised waste treatment off-site compared with direct disposal.

From previous projects, the following remarks can be made:

- Concrete from decontamination of buildings are likely to some extent be subject to clearance. This experience is from earlier Swedish settlement projects (ACL at Studsvik, etc.). With conditional clearance should most of this concrete be released for unrestricted use provided a planned management and well-conducted activity determination.
- Isolation and asbestos could also largely be released for unrestricted use provided a well-executed disassembly.
- Ground remediation, a large proportion of the material can be subject to clearance.

The secondary waste generated in the treatment process includes an estimated quantity of unsorted waste that must be sent to the repository.

4.15.2 Costs and potential savings

It is always difficult to accurately estimate the total cost early in a decommissioning project. The same goes for the possibility to assess the total waste costs. A well-known experience from completed decommissioning projects is that a key factor in the overall cost development during the project is related to how well the project stays on schedule. A delayed project will be more expensive.

The rough estimated cost per tonne, see Chapter 4.11, for the treatment of 1 703 tonne give a total treatment cost of MNOK 43−51 MNOK. This amount does not include any ILW waste, nor transportation costs.

A reduction of the required final disposal volume of 3 380 DE, at a disposal cost of kNOK/DE 20 [D065], will lead to a reduction of disposal costs by approximately MNOK 68, which exceeds the waste treatment cost.

5 Conclusions

In this report, the proposed treatment concept has been evaluated for three different options including both on-site and off-site radwaste management. The concept involves a high recovery rate and a greatly reduced amount of waste that must be disposed of.

The three RWM options have many requirements in common regarding equipment, staffing, competence, logistics, and, transport. However, the degree of implementation differs naturally between the options. This Task 3-assessment shows that all options could be implemented but with different impacts on number of drums for disposal at Himdalen, overall cost for the waste treatment, and time schedule.

Already in the planning phase, it needs to be investigated more thoroughly the volumes of waste that needs to be taken care of and their category. Several gaps and uncertainties have been identified in existing data.

Both cost-wise and regarding drums to be disposed at Himdalen, the assessed options differ significantly. The estimated range of disposal volumes and costs for the three options are:

Volumes:	2 709−4 344 drum equivalents
Costs:	MNOK 183−268

Lowest cost and with lowest waste volumes for disposal is option b estimated to have. The most expensive option is estimated to be option c. The most volume for disposal is option a estimated to have.

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Appendices

Table of content

A Waste management facilities on- and off-site

According to the concept described in the report (and independent of RWM option as in this report), some waste handling (after dismantling and demolition, and if necessary, disintegration and division into categories of risk) is proposed to take place in Halden and Kjeller. This is mostly applicable for the waste that has been deemed to belong to the risk categories Extremely low risk and low risk. Challenges for the on-site waste handling are also related to logistics (getting the waste out from the facility), while maintaining the necessary documentation and traceability of the waste.

Even for other risk categories (LLW and ILW), the handling in Halden and Kjeller will affect the subsequent planned waste management, independent of RWM option. It is therefore of great importance to management in Halden and Kjeller, to work in close collaboration with Himdalen (all options) and the off-site facility (option b) to ensure an optimal categorization, handling, packing and information gathering before the waste leaves the area for transport to Himdalen or to a facility off-site.

A.1 Permissions

IFE has several facilities handling low-level radioactive waste in the daily operation. All facilities have all necessary permits to handle waste, No additional permit is foreseen as needed from a waste handling perspective, since the overall decommissioning license will cover waste handling permits.

New permits will be required to realize the concept in the report, if the state of conditional clearance (e.g., decay storage) will be used.

If an off-site facility will be used, the facility needs permits to:

- Receive waste from IFE.
- Perform the waste treatment.
- Send back secondary waste and waste that cannot be treated.
- Free-release of material (can be conditional and un-conditional).
    - Decay storage when necessary.

A.2 RWM facility on-site

Waste handling in a dedicated facility is needed both at Halden and at Kjeller during the decommissioning, and could be equipped differently depending on the chosen option. As a minimum, the waste handling facility needs to include equipment, routines, staff, and competence for waste management as follows:

- Dismantling
- Segmentation
- Decontamination
    - Wet and or dry
- Compaction
- Packing into boxes and container
- Conditioning
- Characterization
    - Sampling and measurement
- Free-release measurements
- Shipping off-site
- Documentation
    - Waste tracking
    - Shipping
    - Clearance

The list in not an absolute requirement for performing waste treatment on-site or not, but the larger the toolbox is the better the results will be.

A.2.1 Halden

A new facility is most likely needed to be built. The general requirements on size, logistics, location, equipment, staff, and competence is considered in the Task 3 assessment, but more detailed specification for the facility is not subject to this phase of the KVU and is not part of this report.

A.2.2 Kjeller

The existing waste management facility at Kjeller is a good base for the overall waste handling at the different facilities during decommission at Kjeller. Also for this site, the general requirements on size, logistics, location, equipment, staff, and competence is considered in the Task 3 assessment, but as for Halden more detailed specification for the facility is not subject to this phase of the project and is not part of this report.

A.3 RWM facility off-site

If using RWM option b, three waste treatment lines are needed to realize the concept described in the report:

1. A treatment line called DFF (Decont and Free-release Facility) is used for waste that can be free-released without melting and will not need incineration.
    a. The DFF is in principle similar to what needs to be performed on-site in option c.
2. Melting is performed for metallic waste that cannot be free-released in the DFF, or when melting has a clear advantage.
3. Incineration is performed for organic waste.

A processing line for ILW materials will not be needed, since ILW conditioning is not considered for any of the material from the IFE facilities, and is not described further in this report. The volumes of ILW is considered to be small and will not have a major influence on the overall decommissioning project.

These treatment lines together with other handling at the off-site facility is needed to implement the concept, with the requirements of the demolition of the Halden and Kjeller sites deemed to impose on waste management.

A.4 RWM facilities – functionality and flow charts

Examples of required functionality for RWM facilities mentioned in Chapter A.3 is given below. Example of flow charts is also given.

A.4.1 DFF

The DFF is needed to accommodate waste where melting or incineration are not to any advantage, and where the waste still can be released. The treatment line includes decomposition / removal and decontamination as needed followed by activity control followed by clearance.

This facility is considered for waste such as galvanized steel, cable, motors and electronic scrap. The process flow is shown in Figure A-1. After reduction decontamination may take place using a commercial industrial washing machine or by blasting. Cables are fragmented to separate metal and other materials. Clearance occurs after activity monitoring and evaluation for clearance for free use or conditional clearance. The waste that does not meet clearance criteria is sent on to another treatment facility or is conditioned for disposal. The facility is equipped with docking stations for containers to ensure a good logistics.

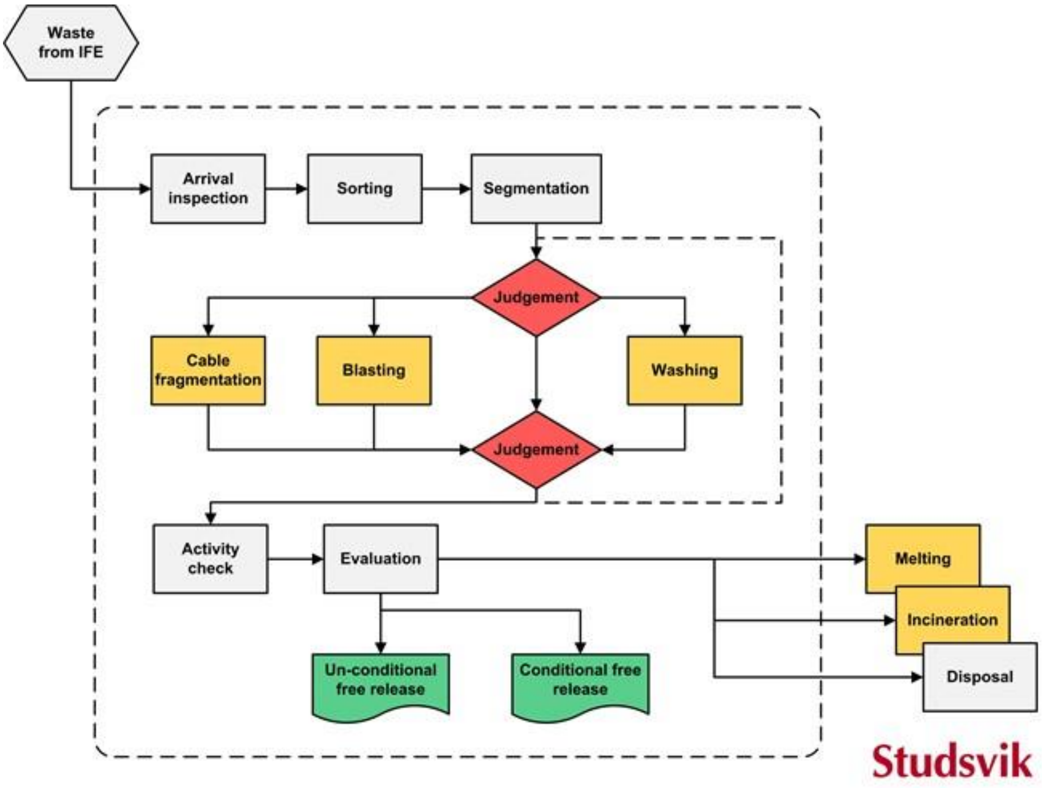

Figure A-1
Flowchart for DFF, which will receive waste not needed to be melted/ burned (e.g. galvanized steel, cable).

Material deemed to be free-released without melting with or without decontamination can be

- Titanium material
- Concrete
- Electric motors
- Electronic waste
- Galvanized steel
- Cable

Many of the materials have a significant material value that is worth considering, such as titanium, aluminium, copper and lead. Material value is both from an economic and from an environmental perspective.

A.4.2 Melting plant

The treatment line includes segmenting, sorting, decontamination and melting of metallic materials. The treatment has two alternative objectives:

- Melting for clearance (free release)
- Melting for volume reduction

The main purpose of melting is free release, and melting is an efficient method for the metal to be free released. The process flow is shown in Figure A-2. Some important parts of the treatment is described in the following sections.

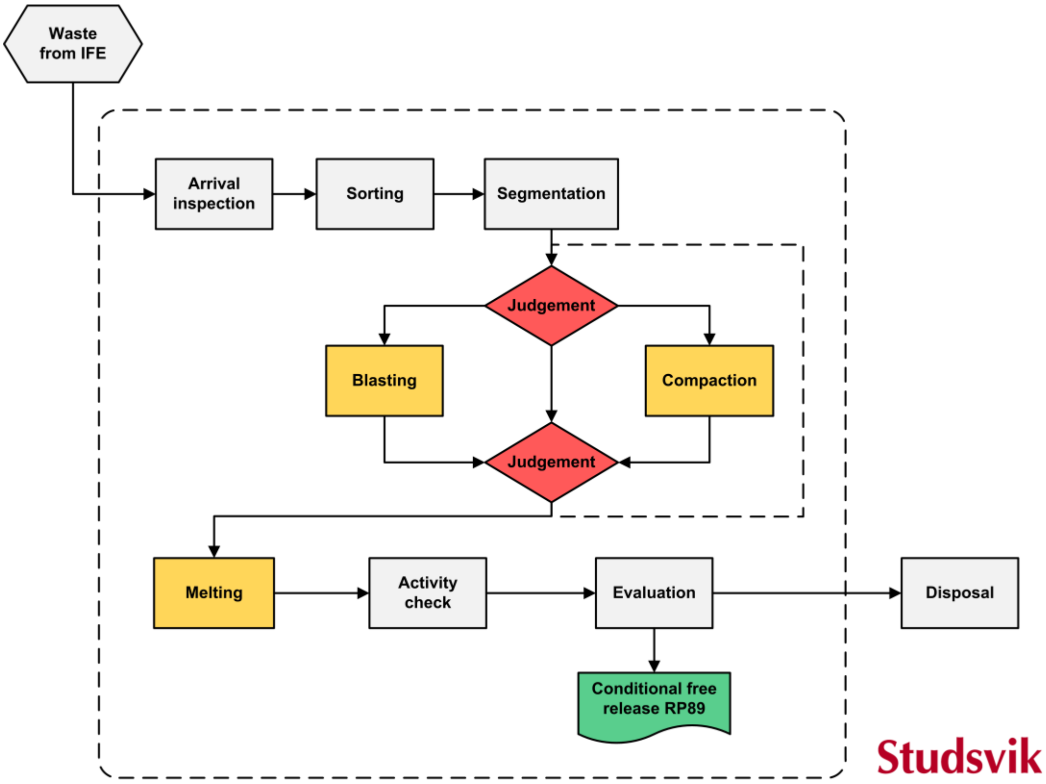

Figure A-2
Flow chart of a melting plant, which will receive the metallic wastes that needs to be melted.

Segmentation

Segmentation is done for several purposes to:

- Enable decontamination
- Open enclosed spaces
- Optimize production flows
- Customize materials for furnaces

Segmentation is done with band saw, scissors or by cutting with hand tools (cutting torch, plasma, etc.).

Decontamination

Normally a variety of equipment for mechanical decontamination of scrap metal are used, such as various types of blasting equipment. The principle is to separate out the bulk of the surface activity by the metal component surface layer is removed. The treatment process generates waste in the form of debris and consumed abrasives.

Melting

Melting of carbon steel, stainless steel, copper, brass, aluminium, and lead occurs batch wise in the furnace.

Furnace capacity by melting batch is (as an example):

- 3 tons of carbon steel and stainless steel
- 3 tons of copper
- 3 ton brass
- 1 ton of aluminium
- 2 tons of lead

Various non-ferrous metals and steel are melted separately. Carbon steel and stainless steel can be melted together. Material is treated in customer-specific campaigns.

In the treatment process occurs secondary waste, see below. Wastes that belong to the customer is returned after the treatment is completed.

Release of the ingot is in accordance with European Commission recommendations, RP 89, according to permission that the facility obtained from the competent authority.

Ingots with an activity content slightly exceeding the limit for clearance can be stored at the facility (off-site) for a period until the activity decays to values below the limits.

Secondary waste is packed in packages approved by IFE.

High-pressure Compaction
High Pressure Compaction is used for such waste which cannot meet clearance criteria or is not being considered for either melting or incineration. For such waste is compaction in many cases a cost-effective way to reduce waste volume. The end product of compaction is a compacted barrel which is then placed in e.g., 200-liter drums, customer specific box or mold.

High Pressure Compaction will in many cases result in a considerable volume reduction.

A.4.3 Incinerator

The incinerator is a treatment approach resulting in ashing of waste. Generated secondary waste is radioactive waste that must be disposed of. Existing facilities are normally used for the low-level organic waste to be incinerated. The process flow is shown in Figure A-3.

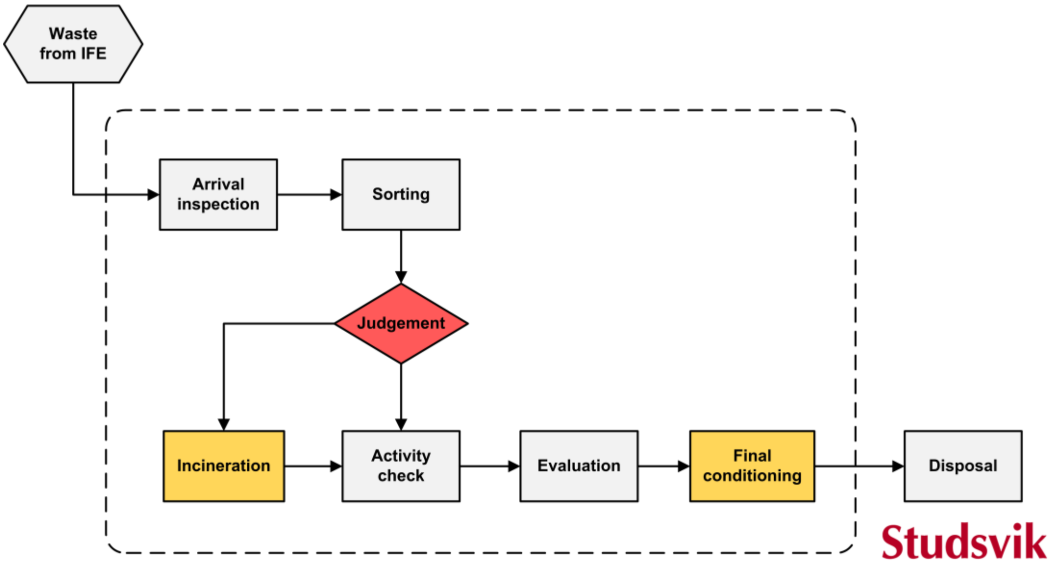

Figure A-3.
Flow chart for the incinerator.

For the incinerator facility applies:

- Before new combustion cycle begins, the ashes from the previous combustion cycle is removed from the collector and transferred to steel drums.
- Following completion of combustion, measurement should be made with respect to the content of radionuclides in the ash. The test results must be recorded.

Ash removal is normally done after a combustion cycle. The ash is transferred to drums that are returned to the customer.

Through combustion, the amount of waste that must be disposed is reduced about a factor of ten by weight and a factor of 30 in volume. It also creates a solid waste suitable for disposal.

A.4.4 Residual

A certain amount of residual waste will remain after the treatment of waste, such as

- Waste that does not meet specifications (outsorted waste or hazardous substances)
- Residues from treated waste
- Secondary wastes from waste treatment
  - Slag from the melting
  - Dust from melting
  - Cutting slag
  - Ashes from the incineration
  - Blasting residues.

The above residual waste belongs to the IFE, but can be conditioned by the facility before final disposal according to standard procedures. From experience, this residual waste constitutes about 5 % of the incoming waste weight.

B Management of waste streams from decommissioning

This appendix gives a short overview of the waste management steps that are expected to be performed on the decommissioning waste for the different waste management options.

B.1 Components

B.1.1 Option Direct disposal

Material that cannot with certainty be assumed to be non-contaminated is segmented into suitable size, packaged and conditioned for disposal. The same applies for materials in the lowest risk categories.

B.1.2 Option Treatment for recycling off-site

The material is sorted based on material properties as well as contamination level.

Metallic waste is in most cases segmented into pieces for easier handling. The fraction that is deemed potentially subject for clearance after decontamination and/or melting goes through suitable treatment steps. Decontamination may include washing in industrial washers and/or blasting.

Non-metallic waste that is deemed potentially subject for clearance after decontamination goes through suitable decontamination steps. This may for example be in industrial washers or cleaning by hand.

Components that consist of several materials may be segmented in material fractions that are treated as per the above. An evaluation whether this is economically justifiable is done on a case by case basis.

The decontaminated/melted material goes through the clearance process. Other material, secondary waste and material that failed clearance are packaged and conditioned for disposal. This step may include, if possible based on material and available equipment, compaction of waste prior to packaging.

B.1.3 Option Treatment for recycling on-site

The waste is segmented/dismantled into manageable size and sorted based on firstly the risk for contamination and secondly the level of contamination.

The fraction that is deemed potentially subject for clearance after decontamination goes through suitable decontamination steps. Based on the material and equipment available, this may for example be washing in industrial washers or by hand for most forms of waste, or blasting of metallic components.

The decontaminated material goes through the clearance process. Material that is not subject to clearance, secondary waste and material that failed clearance are packaged and conditioned for disposal. This step may include, if possible based on material and available equipment, compaction of waste prior to packaging.

B.2 Pipes

B.2.1 Option Direct disposal

Material that cannot with certainty be assumed to be non-contaminated is segmented into suitable size, packaged and conditioned for disposal.

B.2.2 Option Treatment for recycling off-site

The material is sorted based on material properties as well as contamination level.

Metal waste is in most cases segmented. The fraction that is deemed potentially subject for clearance after decontamination and/or melting goes through suitable treatment steps. Decontamination may include washing in industrial washers and/or blasting if possible.

Non-metallic waste that is deemed potentially subject for clearance after decontamination goes through suitable decontamination steps. This may for example be washing in industrial washers or by hand.

Components that consist of several materials may be segmented in material fractions that are treated as per the above. An evaluation whether this is economically justifiable is done on a case by case basis.

The decontaminated/melted material goes through the clearance process. Other material, secondary waste and material that failed clearance are packaged and conditioned for disposal. This step may include, if possible based on material and available equipment, compaction of waste prior to packaging.

B.2.3 Option Treatment for recycling on-site

The waste is segmented/dismantled into manageable size and sorted based on the level of contamination.

The fraction that is deemed potentially subject for clearance after decontamination goes through suitable decontamination steps. Based on the material and equipment available, this may for example be washing in industrial washers or by hand for most forms of waste, or blasting of metallic components.

The decontaminated material goes through the clearance process. Other material, secondary waste and material that failed clearance are packaged and conditioned for disposal. This step may include, if possible based on material and available equipment, compaction of waste prior to packaging.

B.3 Structural steel

B.3.1 Option Direct disposal

Material that cannot with certainty be assumed to be non-contaminated is segmented into suitable size, packaged and conditioned for disposal.

B.3.2 Option Treatment for recycling off-site

The material is sorted based on material properties as well as contamination level.

Metallic waste is in most cases segmented. The fraction that is deemed potentially subject for clearance after decontamination and/or melting goes through suitable treatment steps. Decontamination may include washing in industrial washers and/or blasting.

Non-metallic waste (if any) that is deemed potentially subject for clearance after decontamination goes through suitable decontamination steps. This may for example be washing in industrial washers or by hand.

Components (if any) that consist of several materials may be segmented in material fractions that are treated as per the above. An evaluation whether this is economically justifiable is done on a case by case basis.

The decontaminated/melted material goes through the clearance process. Other material, secondary waste and material that failed clearance are packaged and conditioned for disposal. This step may include, if possible based on material and available equipment, compaction of waste prior to packaging.

B.3.3 Option Treatment for recycling on-site

The waste is segmented/dismantled into manageable size and sorted based on the level of contamination.

The fraction that is deemed potentially subject for clearance after decontamination goes through suitable decontamination steps. Based on the material and equipment available, this may for example be washing in industrial washers or by hand for most forms of waste, or blasting of metallic components.

The decontaminated material goes through the clearance process. Other material, secondary waste and material that failed clearance are packaged and conditioned for disposal. This step may include, if possible based on material and available equipment, compaction of waste prior to packaging.

B.4 Cabling, chutes

B.4.1 Option Direct disposal

Material that cannot with certainty be assumed to be non-contaminated is segmented into suitable size, packaged and conditioned for disposal.

B.4.2 Option Treatment for recycling off-site

Cabling is disassembled in its material fractions using a cable shredder. The metal is largely to be subject for clearance. The lining (cable insulation) is decontaminated e.g. through washing if needed before eventually being subject for clearance. If clearance is deemed not possible it can be sent to the incinerable waste stream.

Cable chutes are treated as components.

Secondary material and material not subject for clearance are returned packaged and ready for disposal.

B.4.3 Option Treatment for recycling on-site

If such equipment is available, cabling is disassembled in its material fractions using a cable shredder. The metal is largely thought to be subject for clearance. The cover sheet (cable insulation) is decontaminated e.g. through washing if needed before being subject for clearance. If clearance is deemed not possible it can be sent to the incinerable waste stream.

If a shredder is not available the cabling may be decontaminated e.g. through washing if deemed potentially subject for clearance.

The decontaminated material goes through the clearance process. Other material, secondary waste and material that failed clearance are packaged and conditioned for disposal.

B.5 Ventilation system

B.5.1 Option Direct disposal

Material that cannot with certainty be assumed to be non-contaminated is segmented into suitable size, packaged and conditioned for disposal.

B.5.2 Option Treatment for recycling off-site

The material is sorted based on material properties as well as contamination level.

Metallic waste is in most cases segmented. The fraction that is deemed potentially subject for clearance after decontamination and/or melting goes through suitable treatment steps. Decontamination may include washing in industrial washers and/or blasting. It should, however, be noted that blasting may not be possible due to material thickness, and that melting of galvanized material is unsuitable due to zinc content.

Non-metallic waste that is deemed potentially subject for clearance after decontamination goes through suitable decontamination steps. This may for example be washing in industrial washers or by hand.

Components that consist of several materials may be segmented in material fractions that are treated as per the above. An evaluation whether this is economically justifiable is done on a case by case basis.

The decontaminated/melted material goes through the clearance process. Other material, secondary waste and material that failed clearance are packaged and conditioned for disposal. This step may include, if possible based on material and available equipment, compaction of waste prior to packaging.

B.5.3 Option Treatment for recycling on-site

The waste is segmented/dismantled into manageable size and sorted based on the level of contamination.

The fraction that is deemed potentially subject for clearance after decontamination goes through suitable decontamination steps. Based on the material and equipment available, this may for example be washing in industrial washers or by hand for most forms of waste, or blasting of metallic components.

The decontaminated material goes through the clearance process. Other material, secondary waste and material that failed clearance are packaged and conditioned for disposal. This step may include, if possible based on material and available equipment, compaction of waste prior to packaging.

B.6 Concrete

B.6.1 Option Direct disposal

Material that cannot with certainty be assumed to be non-contaminated is segmented into suitable size, packaged and conditioned for disposal.

B.6.2 Option Treatment for recycling off-site

Concrete is, if needed for purpose of management and measurement, crushed into rubble. If this is performed reinforcement may be separated as well.

Concrete is not further treated and goes through the clearance process.

Concrete that is activated or contaminated beyond levels where clearance is possible do not benefit from off-site treatment.

Concrete that failed clearance are packaged and conditioned for disposal.

B.6.3 Option Treatment for recycling on-site

Concrete is, if needed for purpose of management and measurement, crushed into rubble. If this is performed reinforcement may be separated as well.

Concrete is not further treated and goes through the clearance process.

Concrete that failed clearance are packaged and conditioned for disposal.

B.7 Reinforcement

B.7.1 Option Direct disposal

Material that cannot with certainty be assumed to be non-contaminated is segmented into suitable size, packaged and conditioned for disposal.

B.7.2 Option Treatment for recycling off-site

Unless physically separated from concrete, the reinforcement is likely to follow the management steps on concrete in which it is embedded.

If extracted from concrete, the majority of reinforcement is likely subject for clearance and undergoes the clearance process after segmentation.

Reinforcement not subject for clearance is packaged and conditioned for disposal.

B.7.3 Option Treatment for recycling on-site

Unless physically separated from concrete, the reinforcement is likely to follow the management steps on concrete in which it is embedded.

If extracted from concrete, the majority of reinforcement is likely subject for clearance and undergoes the clearance process after segmentation.

Reinforcement not subject for clearance is packaged and conditioned for disposal.

B.8 Incinerable

B.8.1 Option Direct disposal

Material that cannot with certainty be assumed to be non-contaminated is segmented into suitable size, packaged and conditioned for disposal.

B.8.2 Option Treatment for recycling off-site

Incinerable waste is transported to a facility for incineration of radioactive waste. The resulting secondary waste, in the form of ashes and dust, are returned after treatment, packaged and conditioned for disposal.

B.8.3 Option Treatment for recycling on-site

A fraction of this material, e.g. protective clothing and other scraps, may be possible to wash in order to reuse the material (may be applicable for all options).

Other material is packaged and, if such equipment is available, compressed into packages. The waste is then conditioned for disposal.

C Task 3-model for waste management

This appendix describes the method used to develop the basis for calculating the amount of waste to be disposed in Himdalen.

It is mainly based on consolidated data in Task 1 report [Huutoniemi, 2014], in which an assessment of waste amounts in various material and activity content categories has been presented.

Based on these data, waste treatment is taken into account by a mass reduction factor, which describes both clearance as well as volume reduction.

The amount of waste is further used to calculate transport and treatment costs. The remaining amount after treatment is used to calculate the number of packages needed, the resulting disposal volume, and the costs associated with these.

The model also takes into consideration on-site investments and other costs that need to be done depending on the treatment method chosen.

The input from Task 1 to the Task 3 model, the judgements made, and the output from the model to Task 4 is summarized in Table C-1.

Table C-1
Task 3 model summary: input, judgments, and, output.

Input	Judgement	Output (input to Task 4)
Contamination class	Waste category	Percentage free releasable per waste stream
Material type	Percentage free releasable	Mass and volume waste to disposal per waste stream
Component type	Mass and volume of secondary waste	Cost for the WT for free release
WAC	Density of secondary waste	Cost for the conditioning for disposal
Masses and volumes of different waste streams	on-site vs. off-site per waste stream	on-site vs. off-site relationship per waste stream
	Is blasting needed?	
	Is segmentation needed?	

C.1 Required input data

The input data for the model are the total waste arising from the decommissioning project, categorized based on the waste stream (type) as well as its distribution over a set of contamination categories.

In Table C-2 below, the basic categorization for waste streams is given.

Table C-2
Waste streams used for the inventory assessment.

Waste stream	Comment
Components	This is a broad category containing several types of objects and process components, such as heat exchangers, pumps, electrical equipment etc. While the material composition varies between these components, the majority is often assumed to be metallic. For most facilities this category is divided into sub-streams based on the component type, while for others it is lumped into only one stream.
Pipes	Piping mainly from process systems. Unless otherwise stated process piping is assumed to consist of steel pipes.
Structural steel	Steel in e.g. walk ways, railing, beams, etc.
Cabling, chutes	Cabling and the associated pathways and chutes. Mainly metallic (steel and copper) but contains e.g. plastic sheets as well.
Ventilation	Ventilation ducts. Metallic or plastic. Steel ducts may be galvanized.
Concrete	The vast majority of concrete consists of bulk concrete in the building structure. However, concrete is also used for radiation protection purposes, e.g. close to the reactor core.
Reinforcement	Steel reinforcement used to reinforce concrete.
Incinerable	Incinerable organic waste such as plastics, rags, scraps etc. This waste stream is also generated during actual decommissioning works.

Furthermore, the waste must be categorized based on its activity inventory through a specific activity of a key nuclide in the material. In this assessment the key nuclide chosen is Co-60. This choice is made since it is commonly the limiting nuclide when assessing treatment alternatives as well as the possibility for clearance of material[1].

Based on the specific activity, the material is categorized into one of six activity content categories as given in Table C-3 below. In the table, an approximate risk category has been included to illustrate the link between the assessment and the general decommissioning approach based on assessment of contamination risk. It should be noted, however, that the two categories are not fully equivalent.

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[1] While the full nuclide content needs to be taken into consideration, Co-60 has a relatively low clearance limit is many jurisdictions and therefore serves as a good nuclide to base preliminary assessments on.

Table C-3
Categorization based on activity content.

Specific activity Co–60 (Bq/g)	Activity content category	Approximate risk category (waste category)	Comment
0	NC (Not Contaminated)	Very low risk (Low risk)	Material that may reasonably be assumed to have a very low or low risk of contamination.
0–1	VLL (Low: Very Low)	Risk (Very Low Level Waste, VLLW)	This category contains material with a very low radioactivity content.
1–20	LL (Low: Low)	(Low Level Waste, LLW)	Material and components with a low radioactivity content. Waste in this category will require decontamination and/or melting in order to be subject for clearance.
20–100	LM (Low: Medium)	(LLW)	Material and components that are contaminated at a moderate level. Part of the waste in this category may be subject for clearance provided that decontamination and/or melting is performed.
100–1 000	LH (Low: High)	(LLW)	Material and components that are contaminated at a moderate but relatively high level. Waste in this category is unlikely to be subject for clearance except in special cases. Melting or other treatment may still reduce volume.
>1 000	H (High)	(ILW)	Material and components that are contaminated at a high level. Waste in this class is not subject for clearance. Treatment for volume reduction may be possible if the material fulfils waste acceptance criteria at the treatment facility.

The input data are given as mass per waste stream and activity inventory category.

C.2 Treatment

Treatment is modelled as a mass reduction factor for each waste stream and activity inventory category.

With this approach the model describes both clearance (through actual reduction of radioactive waste mass) as well as volume reduction (a reduction in mass leads to a corresponding reduction in packaging volume).

In Tables C-4 to C-6 the mass reduction factors are given for each of the three treatment options.

Table C-4
Mass reduction factors for option *direct disposal.*

	NC	VLL	LL	LM	LH	H
Components	100 %	0 %	0 %	0 %	0 %	0 %
Pipes	100 %	0 %	0 %	0 %	0 %	0 %
Structural steel	100 %	0 %	0 %	0 %	0 %	0 %
Cabling, chutes	100 %	0 %	0 %	0 %	0 %	0 %
Ventilation	100 %	0 %	0 %	0 %	0 %	0 %
Concrete	100 %	0 %	0 %	0 %	0 %	0 %
Reinforcement	100 %	0 %	0 %	0 %	0 %	0 %
Incinerable	100 %	0 %	0 %	0 %	0 %	0 %

Table C-5
Mass reduction factors for Option Treatment for recycling *off-site.*

	NC	VLL	LL*	LM*	LH	H
Components	100 %	95 %	95 %	50 %	0 %	0 %
Pipes	100 %	95 %	95 %	50 %	0 %	0 %
Structural steel	100 %	95 %	95 %	50 %	0 %	0 %
Cabling, chutes	100 %	95 %	95 %	95 %	50 %	0 %
Ventilation	100 %	25 %	25 %	0 %	0 %	0 %
Concrete	100 %	75 %**	0 %	0 %	0 %	0 %
Reinforcement	100 %	95 %	95 %	50 %	0 %	0 %
Incinerable	100 %	95 %	95 %	95 %	50 %	0 %

*) 20 years decay storage is assumed part of a conditional clearance.
**) Conditional clearance is assumed.

Table C-6
Mass reduction factors for Option Treatment for recycling *on-site.*

	NC	VLL	LL	LM	LH	H
Components	100 %	25 %	0 %	0 %	0 %	0 %
Pipes	100 %	25 %	0 %	0 %	0 %	0 %
Structural steel	100 %	25 %*	0 %	0 %	0 %	0 %
Cabling, chutes	100 %	25 %	0 %	0 %	0 %	0 %
Ventilation	100 %	25 %	0 %	0 %	0 %	0 %
Concrete	100 %	25 %	0 %	0 %	0 %	0 %
Reinforcement	100 %	25 %	0 %	0 %	0 %	0 %
Incinerable	100 %	25 %	0 %	0 %	0 %	0 %

*) Can be higher, will depend of blasting efficiency and available equipment.

Note that for all waste streams the NC activity category has a 100 % mass reduction rate. This reflects the certainty with which the material has been classified as non-contaminated and therefore should be subject for clearance without significant problems.

Also note that for the recycling off-site option, cabling and chutes has a large mass reduction across all activity categories. This reflects the likelihood that any contamination is mainly on the outer plastic sheet, which during off-site treatment likely is removed. Thereby the largely non-contaminated metal inside is exposed, which ought to be subject for clearance.

The large mass reduction factor for incinerable material in the off-site treatment option reflects the large mass reduction achieved through incineration.

The output from the treatment model is the remaining mass in each waste stream and activity inventory category.

C.3 Packaging

Based on the remaining waste amount after treatment, the resulting waste volume is calculated based on a given packaging efficiency according to Table C-7 below.

Table C-7
Packaging efficiencies for the waste streams.

Waste stream	Bulk packaging efficiency (m^3/ton)
Components	1
Pipes	1
Structural steel	1
Cabling, chutes	1
Ventilation	1
Concrete	0.82
Reinforcement	1
Incinerable	2

Note that in this assessment, no differentiation has been made between the activity categories. In reality, for most waste streams the packaging efficiency is reduced for higher activity categories as the packages contain more radiation protection. Due to a lack of container specifications this has not, however, been taken into account. It will however, have a small overall effect on the volume.

The specific type of waste container that is used has not been specified since all costs are based on the resulting bulk volume of the waste packages.

C.4 Calculation of costs

Based on data in each step as given above, a number of costs associated with the waste management are calculated. These are summarized in Table C-8 below.

Table C-8
Calculation of costs associated with waste management.

Cost	Description	Type
Investment	This cost reflects investments that must be performed, e.g. regarding infrastructure, in order to manage the decommissioning waste.	Fixed cost.
Treatment and conditioning	Cost associated with treatment and conditioning of waste. Manpower and/or vendor costs. Note that this cost is calculated on the total amount of waste excluding the NC activity category.	Cost per unit weight.
Administrative	Cost of administrative tasks associated with waste management, such as measurements, documentation etc.	Cost per unit weight.
Transport	Cost associated with transport of waste from the decommissioned facility either to an off-site treatment facility and/or to disposal.	Cost per unit weight and distance.
Packaging	Cost of packages for waste intended for disposal.	Cost per unit volume.
Disposal	Cost of disposal.	Cost per unit volume.
Decontamination and dismantling of waste management areas/facilities	Cost associated with decommissioning and dismantling of the infrastructure used during the waste management.	Fixed cost.

Together the associated costs are used to calculate the total cost for the waste management of the decommissioning project. Note that several of the cost parameters depend on the waste management option that is being considered.

C.5 Output to Task 4

The Task 3 output to Task 4 Cost Estimate and scheduling is as follows:

- Waste volumes per RWM option and facility to be disposed at Himdalen
- Associated costs for the RWM per option and facility.

D Compilation of decommissioning waste data

This chapter presents detailed tables on the amount (mass and volume) of waste for disposal depending on the waste management option. These data are given for each waste stream in each facility separately in Tables D-1 to D-9 below.

D.1 Halden

Table D-1
Decommissioning waste mass and volume for each waste stream and waste management option, HBWR.

Category	Total excl NC (tonne)	Direct disposal (tonne)	Direct disposal (drum eq.)	Recycling off-site (tonne)	Recycling off-site (drum eq.)	Recycling on-site (tonne)	Recycling on-site (drum eq.)
Components	250.9	250.9	1 195.0	175.4	836.0	246.1	1 172.0
Pipes	8.3	8.3	40.0	6.9	33.0	8.3	40.0
Ventilation	30.0	30.0	143.0	22.5	108.0	30.0	143.0
Cabling, chutes	30.0	30.0	143.0	1.5	8.0	22.5	108.0
Structural steel	20.0	20.0	96.0	1.0	5.0	15.0	72.0
Reinforcement	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reinforcement (bioshield)	8.0	8.0	39.0	8.0	39.0	8.0	39.0
Concrete	124.0	124.0	485.0	31.0	122.0	93.0	364.0
Concrete (bioshield)	380.0	380.0	1 484.0	380.0	1 484.0	380.0	1 484.0
Incinerable	50.0	50.0	477.0	2.5	24.0	37.5	358.0
Total	**901.2**	**901.2**	**4 102.0**	**628.8**	**2 659.0**	**840.4**	**3 780.0**

Table D-2
Decommissioning waste mass and volume for each waste stream and waste management option, Bunker building.

Category	Total excl NC (tonne)	Direct disposal (tonne)	Direct disposal (drum eq.)	Recycling off-site (tonne)	Recycling off-site (drum eq.)	Recycling on-site (tonne)	Recycling on-site (drum eq.)
Components	15.1	15.1	72.0	0.8	4.0	11.8	57.0
Pipes	0.1	0.1	1.0	0.0	1.0	0.1	1.0
Ventilation	0.3	0.3	2.0	0.2	2.0	0.3	2.0
Cabling, chutes	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Structural steel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reinforcement	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Concrete	15.0	15.0	59.0	3.8	15.0	11.3	44.0
Total	**30.5**	**30.5**	**134.0**	**4.7**	**22.0**	**23.5**	**104.0**

Table D-3
Decommissioning waste mass and volume for each waste stream and waste management option, Storage tunnel.

Category	Total excl NC (tonne)	Direct disposal (tonne)	Direct disposal (drum eq.)	Recycling off-site (tonne)	Recycling off-site (drum eq.)	Recycling on-site (tonne)	Recycling on-site (drum eq.)
Cabling, chutes	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Concrete	7.0	7.0	28.0	1.8	7.0	5.3	21.0
Total	**7.0**	**7.0**	**28.0**	**1.8**	**7.0**	**5.3**	**21.0**

Table D-4
Decommissioning waste mass and volume for each waste stream and waste management option, Laundry building.

Category	**Total excl NC (tonne)**	**Direct disposal (tonne)**	**Direct disposal (drum eq.)**	**Recycling off-site (tonne)**	**Recycling off-site (drum eq.)**	**Recycling on-site (tonne)**	**Recycling on-site (drum eq.)**
Components	0.1	0.1	1.0	0.0	1.0	0.1	1.0
Pipes	0.4	0.4	2.0	0.0	1.0	0.3	2.0
Ventilation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cabling, chutes	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Structural steel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reinforcement	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Concrete	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**0.5**	**0.5**	**3.0**	**0.0**	**2.0**	**0.4**	**3.0**

Table D-5
Decommissioning waste mass and volume for each waste stream and waste management option, Metallurgical laboratory.

Category	**Total excl NC (tonne)**	**Direct disposal (tonne)**	**Direct disposal (drum eq.)**	**Recycling off-site (tonne)**	**Recycling off-site (drum eq.)**	**Recycling on-site (tonne)**	**Recycling on-site (drum eq.)**
Components	3.0	3.0	15.0	0.2	1.0	2.3	11.0
Pipes	0.1	0.1	1.0	0.0	1.0	0.1	1.0
Ventilation	0.1	0.1	1.0	0.1	1.0	0.1	1.0
Cabling, chutes	0.3	0.3	2.0	0.0	1.0	0.2	2.0
Structural steel	0.5	0.5	3.0	0.0	1.0	0.4	2.0
Reinforcement	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Concrete	14.0	14.0	55.0	3.5	14.0	10.5	41.0
Total	**18**	**18**	**77**	**3.77**	**19**	**13.55**	**58**

D.2 Kjeller

Table D-6
Decommissioning waste mass and volume for each waste stream and waste management option, JEEP-2.

Category	Total excl NC (tonne)	Direct disposal (tonne)	Direct disposal (drum eq.)	Recycling off-site (tonne)	Recycling off-site (drum eq.)	Recycling on-site (tonne)	Recycling on-site (drum eq.)
Concrete	202.3	202.3	790.0	163.1	637.0	189.2	739.0
Concrete – replaced top cover	13.0	13.0	51.0	13.0	51.0	13.0	51.0
Reinforcement	5.1	5.1	25.0	5.1	25.0	5.1	25.0
Structural steel	15.0	15.0	72.0	0.8	4.0	11.3	54.0
Cables. chutes	17.6	17.6	84.0	0.9	5.0	13.2	63.0
Components – Electric components	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Components – Electric cabinets	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Components – Overhead cranes	31.0	31.0	148.0	1.6	8.0	23.3	111.0
Components – Actuators and valves	13.1	13.1	63.0	0.7	4.0	11.9	57.0
Components – Pumps	2.5	2.5	12.0	0.1	1.0	2.3	11.0
Components – Misc.	3.6	3.6	18.0	0.2	1.0	3.3	16.0
Components – Heat exchangers	8.7	8.7	42.0	0.4	3.0	7.9	38.0
Components – Tanks	19.8	19.8	95.0	1.0	5.0	18.0	86.0
Components – Insulation	6.1	6.1	30.0	0.3*	2.0*	4.6	22.0
Components – RPV	0.6	0.6	3.0	0.6	3.0	0.6	3.0
Components – Reactor internals	2.5	2.5	12.0	2.5	12.0	2.5	12.0
Components – Thermal shield	9.4	9.4	45.0	9.4	45.0	9.4	45.0
Ventilation	30.0	30.0	143.0	22.5	108.0	30.0	143.0
Pipes	6.7	6.7	32.0	0.3	2.0	6.1	29.0
Incinerable	20.0	20.0	191.0	1.0	10.0	15.0	143.0
Total	**407.0**	**407.0**	**1 856.0**	**223.4**	**926.0**	**366.5**	**1 648.0**

*) Assuming conditional clearance.

Table D-7
Decommissioning waste mass and volume for each waste stream and waste management option, ML1.

Category	**Total excl NC (tonne)**	**Direct disposal (tonne)**	**Direct disposal (drum eq.)**	**Recycling off-site (tonne)**	**Recycling off-site (drum eq.)**	**Recycling on-site (tonne)**	**Recycling on-site (drum eq.)**
Components – Misc.	0.027	0.027	1.0	0.001	1.0	0.020	1.0
Components – Other metallic	0.177	0.177	1.0	0.009	1.0	0.132	1.0
Ventilation	0.008	0.008	1.0	0.000	1.0	0.006	1.0
Total	**0.212**	**0.212**	**3.0**	**0.011**	**3.0**	**0.159**	**3.0**

Table D-8
Decommissioning waste mass and volume for each waste stream and waste management option, ML2.

Category	**Total excl NC (tonne)**	**Direct disposal (tonne)**	**Direct disposal (drum eq.)**	**Recycling off-site (tonne)**	**Recycling off-site (drum eq.)**	**Recycling on-site (tonne)**	**Recycling on-site (drum eq.)**
Concrete	70.0	70.0	274.0	70.0	274.0	70.0	274.0
Reinforcement	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable, chutes	1.8	1.8	9.0	0.1	1.0	1.4	7.0
Components – Electric components	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Components – Handling equipment	3.8	3.8	19.0	2.9	14.0	3.6	17.0
Components – Actuators and valves	0.4	0.4	2.0	0.0	1.0	0.3	2.0
Components – Pumps	0.2	0.2	1.0	0.0	1.0	0.1	1.0
Components – Heating and sanitation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Components – Tanks	2.0	2.0	10.0	2.0	10.0	2.0	10.0
Components – Overhead cranes	12.0	12.0	58.0	0.6	3.0	9.0	43.0
Components – Misc.	77.0	77.0	367.0	35.4	169.0	70.0	334.0
Components – Other metallic	50.7	50.7	242.0	45.4	217.0	50.6	241.0
Ventilation	5.9	5.9	29.0	5.9	29.0	5.9	29.0
Pipes – Heating and sanitation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Incinerable	11.0	11.0	105.0	0.6	6.0	8.3	79.0
Total	**234.7**	**234.7**	**1 116.0**	**162.8**	**725.0**	**221.1**	**1 037.0**

Table D-9
Decommissioning waste mass and volume for each waste stream and waste management option, RW.

Category	Total excl NC (tonne)	Direct disposal (tonne)	Direct disposal (drum eq.)	Recycling off-site (tonne)	Recycling off-site (drum eq.)	Recycling on-site (tonne)	Recycling on-site (drum eq.)
Concrete	29.4	29.4	115.0	7.3	29.0	22.0	87.0
Reinforcement	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable. chutes	2.0	2.0	10.0	0.1	1.0	1.5	8.0
Components – Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Components – Actuators and valves	0.4	0.4	2.0	0.0	1.0	0.3	2.0
Components – Pumps	0.1	0.1	1.0	0.0	1.0	0.1	1.0
Components – Heating and sanitation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Components – Tanks	4.0	4.0	20.0	4.0	20.0	4.0	20.0
Components – Misc.	45.0	45.0	215.0	2.3	11.0	34.9	167.0
Ventilation	8.5	8.5	41.0	0.4	3.0	6.4	31.0
Pipes	1.0	1.0	5.0	0.1	1.0	1.0	5.0
Pipes – Heating and sanitation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Incinerable	5.0	5.0	48.0	0.3	3.0	3.8	36.0
Plastic/Incinerable (NALFA pipes)	8.0	8.0	39.0	0.4	2.0	6.0	29.0
Total	**103.3**	**103.3**	**496.0**	**14.8**	**72.0**	**79.9**	**386.0**