NND Future Waste Management Program

The Future WMP for radioactive- and decommissioning waste

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Summary

Within a few years NND intends to take over responsibility for handling all Norwegian radioactive waste and the decommissioning waste from the Norwegian (IFE) research reactor facilities. This report gives an overview of how the material will be treated, stored and disposed.

This Waste Management Program (WMP) is written to fulfil DSA's concession requirement no. 13 regarding waste management. The document is thus in firsthand aimed to DSA, but it will work also internally, and in relation to other stakeholders, to conclude NND's intentions and present status regarding waste management matters.

This document shows on a conceptual level how NND plans to handle the chain of actions and facilities required to move from the present situation, via waste handling and storage to disposal of radioactive waste. It gives an overview of applicable regulations. It gives a short description of the planned treatment, storage and disposal of the radioactive and non-radioactive wastes incoming from both society in general and the dismantling and demolition of nuclear facilities. The document is founded on the current Waste Management Program [1] which handles the situation where IFE's facilities are still in operation.

The WMP shows how the waste is divided into categories and activity classes and how treatment is handled with regards to each category and class. It points out nine different waste streams, out of which two also have subdivisions for different treatment tracks. Planning of the treatment is based on, for example, activity content, type of adherence, radiation safety and waste hierarchy. For spent nuclear fuel (SNF), nuclear safety and safeguard concerns also apply.

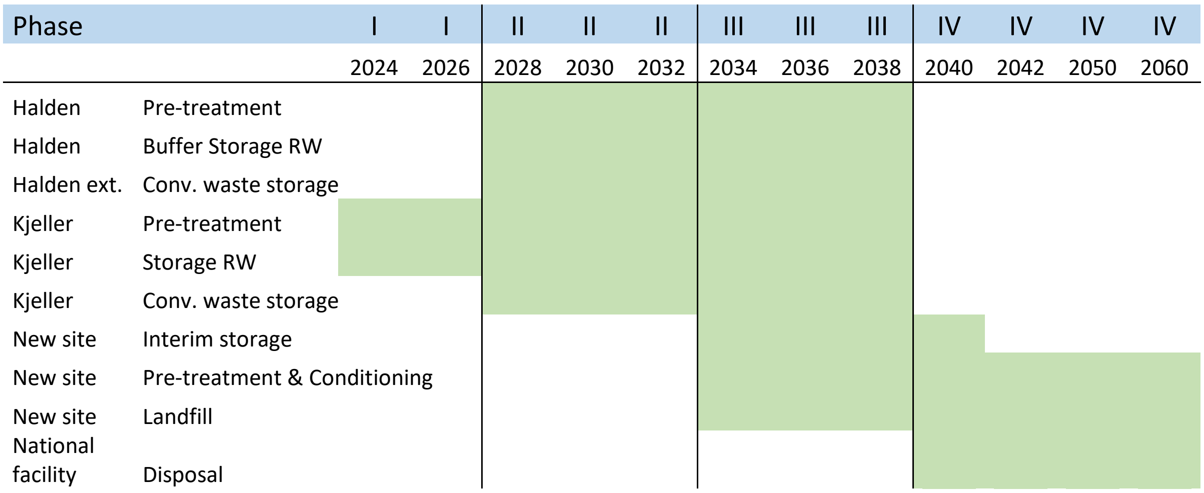
The division into different waste streams is based on the EU-directives' waste hierarchy triangle, where reuse and recycling are advocated as far as possible. The document shows that only a few per cent of the waste need treatment, storage and successively disposal. This means the bulk of the material should be able to pass clearance, which allows conventional recycling.

The need for treatment and storage space at the existing sites requires sufficient facilities. Construction and commencement of these require extensive licensing measures towards several different stakeholders. In certain cases these stakeholders might also need to influence each other in order to enhance progress. It has to be emphasized that these additional facilities should only remain as long as the decommissioning lasts, i.e. they are planned to be removed again within around two decades so that the sites can be restored and cleared from regulatory control.

In order to be able to plan the needed facilities the waste treatment is divided into four different phases, where each stage represents availability to certain facilities:

Phase 1: Today's situation, but with enhanced clearance capabilities
Phase 2: Additional facilities available at existing sites
Phase 3: New site available with treatment station and interim storage
Phase 4: National disposal facility available

This can be illustrated in accordance with the following figure, where the years given as milestones should be seen as a first estimation:



The table shows that the waste management is very dependent on commissioning of additional facilities on both the existing sites, the planned new site and later on the National disposal facility. These needed new facilities all require competent licensing to be prioritized.

The focus during the first years should be to employ needed personnel, get an overview of the dismantling and the waste management market, build up relations to partners and contractors as well as preparing contracts to relevant companies. Other important areas are to get an overview of the material, e.g characterize the future waste and to prepare the sites through e.g. system decontamination and POCO. It is also to establish procedures and prepare both physical and administrational infrastructure for the coming decommissioning. The production of waste will thus not be a primary concern during phase 1, which gives a few years to prepare needed facilities for waste management.

The WMP is written on a conceptual level based on the knowledge available today. The WMP is intended as a “living document”, i.e., it should be updated when new, or changed, information is available, such as for example during later design stages, after receival of results from the characterization project, or development of WAC for waste facilities..

- The concept should be further developed in dedicated projects, in Basic and subsequently Detail design.
- The document also has no intention of listing all necessary requirements, which should be handled within the Requirement management part of the programme.
- Sizes and capacities for the needed facilities will be updated in accordance with Basic design and developed within dedicated projects.

Conclusions of material and treatments are given in chapter 6.4 whereas broader conclusions and recommendations are given in chapter in chapter 11, together with suggestions for stronger implementation of the Requirement management work.

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conv.	conventional, i.e. non-nuclear
DSA	Direktoratet for strålevern og atomsikkerhet (The Norwegian Radiation Protection and Nuclear Safety Authority)
DSRS	Disused sealed radioactive sources
EEA	European economic area
EIA	Environment impact assessment
ESP	Extern service provider
ETD	Easy to decontaminate
GLC	General license criteria
GSR	IAEA's General safety requirements
HBWR	Halden Boiling Water Reactor
HEU-Th	Highly enriched uranium/thorium
HLW	High Level Waste
IER	Ion exchange resin
IFE	Institute for Energy Technology
ILW	Intermediate Level Waste
KLDRA	Kombinert lager og deponi for lav- og mellomaktivt radioaktivt avfall (Combined Storage and Disposal Facility for Low- and Intermediate Level Waste)
LARA	Lager for radioaktivt avfall, (NND project, Storage for RW)
LILW	Low- and Intermediate Level Waste
LLW	Low Level Waste
MMC	Mobile Melt Consolidate
mSv	Millisievert
NFD	Nærings- og fiskeridepartementet (Ministry of Trade, Industry and Fisheries)
NND	Norsk nukleær dekommisjonering (Norwegian Nuclear Decommissioning)
NNSA	National nuclear security administration (USA)
NORM	Naturally Occurring Radioactive Material
PIE	Post-irradiation examination
PJD	Post job debriefing
POCO	Post operation clean out
RH	Reactor hall
ROS	Risiko- og sårbarhetsanalyse (Risk and vulnerability analysis)
RW	Radioactive waste
RWM	Radioactive waste management
SCB's	The Light water subcoolers at HBWR
SD	Steam drum
SG	Steam generator
SNF	Spent Nuclear Fuel
SRNL	Savannah river national laboratory
ST´s	Steam transformers
UMA	Utredning om midlertidig lager og avfallsbehandling (NND project, Investigation on Interim storage and waste treatment facility)
VLLW	Very Low-Level Waste

VSLW	Very short lived waste
WAC	Waste Acceptance Criteria
WMP	Waste Management Program
WS	Waste stream

List of definitions

Buffer storage	The short term (hours, days, weeks) storages existing and/or to be added to the existing sites at Halden and Kjeller. To be used while waiting for available personnel, signatures, decisions or transports. These storages should be used during decommissioning of today's sites and after that decommissioned.
Site storage	A larger storage space on each site where the waste is stored a number of years until the Interim storage is available to receive waste. These storages are to be decommissioned again within around 15 years as one of the later parts of the decommissioning of today's sites.
Interim storage	The long term (years, decades) storage developed through the UMA and LARA projects. It is planned to be sited within the Halden or Aremark municipalities and will serve as a site for storage of RW until sufficient disposal for RW is commissioned. The site will include facilities for waste treatment to be used during decommissioning and after the current RWM facilities in Kjeller are decommissioned. The site might also include a landfill for disposal of VLLW and similar.
National disposal facility	The site for geological disposal of LLW, ILW, HLW and SNF that will be deployed in the form of DBD or DGR. Not to be mixed with various landfill-type disposals.
Specific activity	Radioactive decay per second, per weight, measured in Bq/g.

1. Introduction

Decommissioning of the Norwegian nuclear facilities will produce large amounts of material that have to be measured, sorted, treated, packed and transported for storage and disposal. The decommissioning material consists of both radioactive waste (RW) and conventional waste. This Waste Management Program (WMP) describes how these are separated and how RW is categorized and classified before further treatment and storage. It also shows on a conceptual level the different treatment methods and facilities that are planned to be used for this waste management. These plans will be evaluated and further developed during design of facilities and methods.

The purpose of this report is to on a general level describe treatment, storage and disposal of both short-lived and long-lived radioactive waste as well as clearance of the non-radioactive waste. It will define headings for the planned handling, waste minimization, processing, transportation, storage and safeguarding related to management of radioactive waste in Norway. This includes waste from operation of the IFE nuclear facilities and waste from other sources of radioactive waste in Norway, as well as waste from decommissioning of the research reactors and associated facilities at Kjeller and Halden.

As decommissioning is started the incoming waste flow will be drastically increased and the decommissioning will thereby have a great impact on the need of infrastructure for handling the waste. Thus, waste management planning has to be done in close cooperation with the decommissioning program.

Operational waste should as far as possible be handled before start of the decommissioning phase. Treatment of decommissioning waste is in most cases handled in the same way as for operational waste. The WMP valid today [1] describes waste treatment and storage solutions for the Norwegian waste during operation of the IFE facilities. By the transfer to decommissioning phase for IFE's facilities this WMP will supersede [1]. Handling of remaining operational waste will be done in accordance with this WMP.

The WMP is developed in accordance with DSA and IAEA directives and guidelines, as described in chapters 1.2 and 2.2.

1.1 Objectives

Formally this document is written to fulfil DSA's general licensing criteria no. 13 and connected requirements regarding the need of a Waste management program. The objective of a Waste management program is to outline treatment, clearance procedures, categorization, packaging, storage, transport and disposal of the radioactive waste that is produced under the decommissioning as well as remaining waste from operation and from other sources.

The objective of waste management is to keep people safe, keep the environment clean and assure that the burden of waste management is not left to coming generations. The waste treatment should thus be conducted in a safe way for both personnel and environment.

NND's strategy for waste management (S*trategi for målområdet avfallshåndtering*) [2] describes the following high-level principles that shall guide waste handling:

> <u>Protection of people:</u> Waste management shall not affect human health. Discharges shall be as low as practically achievable and be less than permitted limits.

Protection of the environment: Waste management shall not have significant impacts om the environment. Discharges shall be minimized, controlled and less than permitted limits.

Protection beyond national boundaries: People and the environment in other countries shall be protected to the same extent as people and the environment in Norway.

Protection of future generations: Radioactive waste shall be managed in a way that ensures that future generations are not subjected to a greater risk than what is acceptable today.

Our generation takes responsibility: The task of managing radioactive waste shall not be transferred to future generations.

Use of known technology and methods (Best available technology, BAT): Waste shall as a main principle be handled by use of internationally recognized and tested technologies and methods.

Social and economic solutions: Waste shall be handled in a rational way and resource expenditure shall be balanced against other risks, environmental effects, costs and other factors.

Complete waste flows: The full life cycle of waste, from production to disposal, shall be planned. Disposal facilities shall be established for all classes of waste managed by NND.

Waste prevention: Generation of radioactive waste shall be kept to a minimum.

The program is not intended to collect and illustrate all necessary requirements, this should be done as part of a formalized requirement management. The document is also not intended to tie together all guidelines and previous documents written regarding waste matters. In short, the document is an outline of the needed actions and facilities.

1.2 Regulatory requirements for a waste management program (WMP)

The Norwegian Radiation and Nuclear Safety Authority (Direktoratet for strålevern og atomsikkerhet, DSA) has defined 25 general licensing conditions. General license condition (GLC) no. 13 states that:

> "The licensee shall implement and maintain a waste management program that documents handling, waste minimization, processing, transportation, storage and safeguarding of radioactive waste, including spent fuel and nuclear waste that is mixed with other hazardous substances." [3]

DSA has further elaborated on the license condition in [4], which is written in Norwegian but can be translated to the following:

> *"The owner of a nuclear facility shall establish and implement a program for the management of radioactive waste, nuclear waste and spent nuclear fuel as well as nuclear waste mixed with other hazardous substances. To the extent relevant, the waste management programme should include the following activities: collection, characterization, classification, processing (pre-treatment, treatment and conditioning), transport and storage of radioactive waste, release of radioactive material and disposal of radioactive waste.*

All activities related to radioactive waste and emissions should be carried out in accordance with the management system and in line with approved procedures.

The facility shall be operated in such a way that the production of radioactive waste of all kinds is as low as possible, that the release of radioactive material to the environment is kept below the limits permitted by the authorities and as low as practicable, and so that the handling and disposal of waste is facilitated.

Emissions shall be monitored, and results recorded to verify compliance with applicable regulatory requirements.

The production of waste, as well as the classification, treatment, storage and transfer of waste, should be documented. An appropriate inventory should be kept of the amounts, types and characteristics of the radioactive waste treated and stored on site or transferred to approved facilities for treatment, storage or disposal.

When a decision is made to store radioactive waste pending further disposal, all available information for waste characterization should be recoverable.
The stringency of waste and discharge sampling and monitoring regimes, including monitoring at source (as close to where waste is produced as practicable) and the frequency with which samples are to be taken, should be determined in accordance with the potential environmental impact of waste and discharge and with a risk-based approach.

The facility shall establish an adequate environmental monitoring programme for monitoring radionuclides in the environment (both from planned and unplanned discharges) and for assessing associated environmental impacts. The environmental monitoring programme should include:

→ establishing background levels before commencement of operations

→ setting action limits

→ establishment of environmental monitoring stations on and off site to monitor surface water, groundwater, soil/sediments and biota

→ documentation, including of emissions, as well as results of audits and inspections."

1.3 Scope

This WMP covers the waste to be handled by NND after NND has taken over responsibility for the national radioactive waste management program today handled by IFE and described in [1]. This means the program is intended to handle all Norwegian radioactive waste as well as all waste from both operation and decommissioning of the Norwegian nuclear research programme. Thus, the program includes:

- Remaining waste from operation of IFE Halden
- Remaining waste from operation of IFE Kjeller
- Decommissioning waste from both IFE facilities
- Incoming industrial waste from Norwegian companies and state entities

- Incoming societal waste, e.g., fire alarms

The following sources are not further handled:

- Naturally Occurring Radioactive Material (NORM) waste from mining and construction works, e.g. Søve gruver [5]

The radioactive waste storage and disposal facility, KLDRA in Himdalen, is under evaluation from its operator IFE. Whether it can be used for further storage is thereby not yet known. [6] However IFE has concluded that it will not be used for further disposal. Stored waste should thereby be handled as any other waste, radiologic measurements should be made, and the materials should be handled with regard to measurement results – either cleared, treated or disposed at a suitable disposal facility.

2. Regulatory framework

2.1 National laws and regulations

Activities related to management of radioactive waste in Norway are regulated by three main laws:

- The Pollution Control Act (Forurensningsloven) (13 March 1981 nr. 6) [7]
- The Nuclear Energy Act (Atomenergiloven) (12 May 1972 nr. 28) [8]
- The Radiation Protection Act (Strålevernloven) (1 July 2000 nr. 36) [9]

These laws are accompanied by regulations, including:

- Regulations on Radiation Protection and Use of Radiation (Strålevernforskriften) (16 Dec 2016 nr. 1659) [10]
- Regulations on Radioactive Pollution and Radioactive Waste (Forskrift om Forurensningslovens anvendelse på radioaktiv forurensning og radioaktivt avfall, 1 Feb 2010 nr. 1394) [11]
- Waste Regulations (Forskrift om gjenvinning og behandling av avfall, Avfallsforskriften, 1 Jun 2004 no. 930) [12]
- Regulations on Physical Protection of Nuclear Material and Nuclear Facilities (Forskrift om fysisk beskyttelse av nukleært materiale og nukleære anlegg, 2 Nov 1984 no. 1809) [13]
- Regulation on Transportation of Dangerous Goods by Land (Forskrift om landtransport av farlig gods), of 1 April 2009 [14]
- Regulation on Dangerous Goods on Norwegian Ships, of 1 July 2014 (Forskrift om farlig last på norske skip) [15]

Operators of radioactive waste management facilities must provide a yearly report which gives an overview over the amount of waste received, conditioned and disposed of, and of waste stored on site. In addition, they have to send reports on waste discharges from the facilities and results from environmental monitoring. Operators must also provide other details of significance to safety and the integrity of the facilities. Many of the requirements for basic waste management (e.g., waste minimization and application of the waste hierarchy) are similar to those for the operator of any facility with a permit under the Pollution Control Act. General criteria for what must be reported are presented in Guidelines for yearly reporting for Operators of radioactive waste management facilities [16] by DSA. Facility specific criteria are included in the permits [17].

The Pollution Control Act

The pollution authorities, cf. The Pollution Control Act § 81, may on application issue a permit for any activity that may lead to pollution, cf. The Pollution Control Act § 11.

The regulations on radioactive pollution and radioactive waste [11] include limits on specific activity above which waste shall be classified as radioactive. The same regulations divide radioactive waste into two categories:

- "RW without disposal obligation": Waste that contains specific activities greater than the limits for radioactive waste, but less specific activity or total annual activity than specified in annex I letter b in the regulations.
- "RW with disposal obligation": Waste that contains specific activity and total annual activity greater than specified in annex I letter b in the regulations.

This is illustrated in Figure 1.

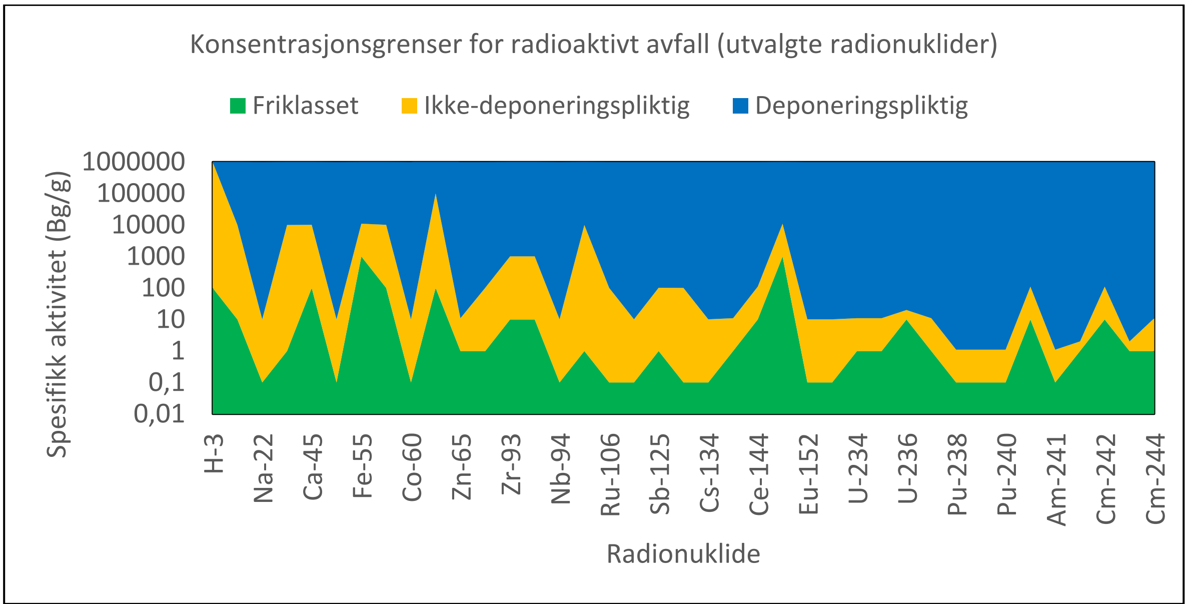

Figure 1: Norwegian limits on specific activity for different waste classes. A subset of nuclides shown.

§2 of the Act states that the implementation of the Act shall take place in accordance with six stated guidelines. Guideline no 4 of these is of significant relevance to the handling of radioactive waste in Norway and for this document:

> *4. Waste must be taken care of so that it causes as little damage and inconvenience as possible. It must be recycled, preferably by preparing it for re-use or material recovery, unless recycling is not justified based on a balance of environmental considerations, resource considerations and economic conditions.*

The waste regulations (Avfallsforskriften) [12] **state the following:**

- Radioactive waste must not be mixed together with other waste, and different types of radioactive waste must not be mixed together if this could entail a risk of contamination or create problems for the further handling of the waste (§ 16-4, second section).
- It is not permitted to dilute radioactive waste with the intention of falling below the limits for radioactive waste (§ 16-4, third section).
- Facilities that handle “RW with disposal obligation" must have a permit from DSA (§ 16-5, first section).
- Facilities that have a permit to handle hazardous waste may handle “RW without disposal obligation” (§ 16-5, second section).
- Producers of radioactive waste must deliver the waste to an approved waste facility or according to a return arrangement for sealed radioactive sources at least once per year (§ 16-7).
- Radioactive waste must be declared, which includes sending a description of the waste to DSA (§ 16-9).
- Import and export of radioactive waste requires a permit from DSA and is only permitted under certain circumstances (§§ 16-11 and 16-12).

The Nuclear Energy Act

The Nuclear Energy Act [8] requires that nuclear facilities have a license according to section 4 and that holders of nuclear substances have a permit to do so. The act also describes the role of DSA (§10), requirements for establishing new facilities (§11), modification of facilities (§12), inspection and orders (§13 and 14), the duty to safeguard against harm (§15), the duty to inform about incidents and accidents (§16) and the responsibility for damages (chapter 3).

Based on the nuclear energy acts §10, DSA has defined 25 general license conditions [3].

The regulations on physical protection of nuclear material and nuclear facilities (Forskrift om fysisk beskyttelse av nukleært materiale og nukleære anlegg) [13] describe more detailed requirements for physical security of nuclear facilities.

The Radiation Protection Act

The Radiation Protection Act [9] sets requirements for radioactive waste management. The Regulations on Radiation Protection and Use of Radiation (Strålevernforskriften) [10] state that exposure to radiation must be justified, as low as practically possible and below given limits cf. §§ 5 and 32. The doses for personnel shall be monitored (§ 33). The regulations set requirements for internal control, competence, instructions, and routines (§ 16). § 21 stipulates that waste facilities must have overview and control of all containers with radioactive waste. § 25 sets requirements for the design and securing of storage spaces, while § 26 sets requirements for shielding and safety equipment.

Regulations on transport of radioactive waste and materials

Transport of radioactive waste in Norway is subjected to the regulations in [14] & [15]. These refer to a large extent to the international regulations ADR (road transport), RID (rail transport) and IMDG (sea transport). The guidelines set requirements for the type of waste containers that can be used, the type of safety equipment that must be available, the documentation that must accompany the transport and various other safety aspects before, during and after transport.

Besides the regulations above, the Nuclear Energy Act covers transport of nuclear material, and the Radiation Protection Act is applicable to the transport of radioactive material.

The IAEA has developed regulations for transport of radioactive materials in SSR-6 [18].

IFE has been granted a license to handle and transport nuclear material through the facility licenses under The Nuclear Energy Act. According to IFE´s requirement document for transport of nuclear material (Kravdokument: Transport av nukleært materiale v2) [19], IFE shall have a graded approach for safety during transport. IFE's requirements are based on requirements defined in the Atomic Energy Act with regulations, the current version of IFE's ROS (Risiko- og sårbarhetsanalyse) for transport as well as recommendations in the IAEA Regulations for the Safe Transport of Radioactive Material (SSR-6) [18]. NND intend to take over applicable licenses and follow the same regulations.

Requirements for physical protection during transport are given in the Nuclear Energy Act regulations on physical protection of nuclear materials and nuclear facilities [13]. This includes requirements for approval of physical security before transport [19].

For transports in accordance with IFE´s requirement document, the requirements are defined by each category of nuclear material [19]. For materials in category 1 or 2, the regulations on physical protection of nuclear materials and nuclear facilities stipulate that protection must be in accordance with "strict administrative practice" [13].

In addition to the regulations in the Nuclear Energy Act, provisions in modal regulations apply. For road transport, there are separate safety provisions in ADR (Chapter 1.10). These safety provisions are in accordance with ADR chapter 1.10.5, to be considered to be fulfilled if the material is transported in accordance with the provisions of the Nuclear Security Convention and IAEA INFCIRC 225 [20] as mentioned in [19].

ADR chapter 1.10.5 [21]:

> *"For radioactive material, the requirements of this chapter are considered to be met if the requirements of the “Convention on the Protection of Nuclear Material” and the IAEA “The Physical Protection of Nuclear Material and Nuclear Facilities” are used."*

Transboundary transport shall be in accordance with the provisions for transport in the countries of transit and in the country of destination. For transports in the Euratom area, transports will be regulated through EU directives [19].

2.2 International regulations and guidelines

Requirement number 9 in IAEA General Safety Requirements (GSR) Part 5 – Predisposal Management of Radioactive Waste [22], states that:

> *“At various steps in the predisposal management of radioactive waste, the radioactive waste shall be characterized and classified in accordance with requirements established or approved by the regulatory body”.*

This is to ensure that proper and adequate provision is made for the safety implications associated with the management and disposal of waste.

The classification scheme developed is focused on solid radioactive waste. However, the fundamental approach could also be applicable to the management of liquid and gaseous waste, with appropriate consideration given to aspects including the processing of such waste to produce a solid waste form that is suitable for disposal.

IAEA recommendations considered in this report include:

- IAEA Classification of Radioactive Waste (GSG-1)
- IAEA Predisposal Management of Radioactive Waste (GSR Part 5)
- IAEA Disposal of Radioactive Waste (SSR-5)
- IAEA Regulations for the safe transport of radioactive material 2018 (SSR-6)
- IAEA Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors (SSG-40)
- IAEA Decommissioning of Nuclear power plants, research reactors and other nuclear fuel cycle facilities (SSG-47)

2.3 IFE internal requirements and principles

As part of the takeover, NND will implement IFE requirements and principles. For example, IFE applies some general principles for waste management and emissions of radioactivity to the environment, valid for all facilities and described in document AV 090 [23] and summarized below for solid and liquid waste.

Treatment of solid waste:

- Solid radioactive waste must be treated so that the volumes and amounts of activity are kept to a minimum. This is achieved by, among other things:
    - Waste reduction measures in processes
    - Sorting of waste into radioactive and non-radioactive waste
    - Storage for decay
    - Technical solutions for volume reduction.

Treatment of liquid waste:

- Semi-liquid waste is treated by transferring it to solid form.
- Liquid radioactive waste shall be treated so that the volumes and amounts of activity are kept to a minimum. This is done by:
    - Waste reduction measures for processes and activities that generate liquid radioactive waste.
    - Storage of radioactive wastewater for decay.
    - Reduction of volumes and activity levels by treatment with technical methods.

Emissions of radioactivity to water and air:

- Emissions of radioactivity to air and water shall not exceed the nuclide-specific emission limits or dose limits in the emission permit pursuant to the Pollution Control Act

- Nuclides and the amount of activity released into water and into air shall be documented.
- Emissions of radionuclides to air shall be reduced as far as possible without unreasonable cost by means of:
    - Waste reduction measures for processes and activities that generate emissions of radioactivity to air.
    - Filtration of radioactive emissions to air.
    - Storage / delay of emissions for decay.

3. NND Decommissioning roadmap [1]

Before decommissioning starts, as many activities as possible should be handled under the operating license. These activities include, for example, Post operational clean-out (POCO) and system decontamination. POCO includes removal of unnecessary loose equipment and spare parts storage etc. It should be evaluated whether it is beneficial to rinse the primary system and certain loop-systems with e.g. oxalic acid to lower the activity in these systems before they are opened and cutting of the piping commences. Decontamination will lower dose rates to dismantling personnel and might also lower the appointed waste class for the system parts, but will generate other wastes from the process.

Decommissioning of the facilities consists of two main activities: dismantling (of systems and components) and demolition (of buildings and structures).

Dismantling is done during main phase of decommissioning and handles first of all metallic waste, which is defined as RW unless otherwise proved. Contaminated surfaces of walls and floors are also included in the dismantling phase and generally contain epoxy painted concrete.

Demolition on the other hand is done after buildings have been cleared from regulatory control. Demolition handles first of all concrete with its rebars, and as clearance has already been done, the waste is not seen as radioactive and can thus be handled through conventional recycling of material.

NND plans to start the decommissioning with dismantling of systems connected to N0RA and JEEP 1. For a start this will be possible to manage within the existing infrastructure for waste treatment and storage. However, to be able to ramp up the work there will later on be a need for enhanced capacity in treatment facilities and storage space as well as a new interim storage facility at a new site. This step will require significant time to achieve with regard to the required licensing of a new site.

3.1 Work packages

The dismantling and demolition will be further divided into a number of different work packages. The work packages are in most cases coherent with the different facilities/buildings. They will be planned to be feasible in time and scope for a contractor to manage without clashes and unclear interfaces to other contractors.

As part of the dismantling work packages the material should be cut down to pieces in order to fit a Berglöfslåda [24] or a similar size box or mold. This has to be done in order to facilitate measurements of the material to determine its content and type of radioactive substances. This has to be done for all material during the dismantling phase. The measurements will decide whether the material can be cleared from regulatory control, if it is fit for conditional clearance, or if it has to be handled as radioactive waste.

After the material has been dismantled, cut down, packed, measured, and labeled, the box/mold will be delivered to an agreed hand-over point. From this point the responsibility is taken over from the dismantling contractor by the NND waste team. Due to the given labels the waste team will appoint the waste to a given waste stream to optimize needed treatment and logistics for each box of waste.

[1] NND Decommissioning strategy [50] is given in the NND management system. This chapter is a further elaboration and concretization of the fundamental headlines given in the strategy document.

The needed waste treatment should preferably be done as close as possible to the waste source. In this way the risks and transports as well as the needed paperwork for transportation is kept ALARA. A limiting factor is the small area available on the Halden site.

As no WAC for the National disposal facility are available, the waste will be stored unconditioned. Thus, there will be no provisions made for final conditioning of the waste. Required space for the future final conditioning of waste shall however be considered at the interim storage facility.

3.2 Overall decommissioning chronology

According to NND's Roadmap (Vegkart) 2050 [25], the dismantling phase is planned to last 180 months, whereas the final conventional demolition is planned to be done in 24 months. These time periods have the same length in all four given cases in the Roadmap. The relatively long time period available will keep down the waste flow, thereby the required area and infrastructure for treatment and logistics can be kept fairly low.

Early dismantling is planned towards the end of the 2020´s whereas commencement of interim storage and ramp up of dismantling pace is foreseen to take place during first half of the 2030´s.

The work is planned to start with a pilot-case, N0RA, to get an understanding of licensing requirements and upcoming problems related to dismantling. Next step will be to clear space for waste treatment, logistics and buffer storages at the sites, e.g. in the JEEP1-building. Dismantling then continues with JEEP 2 and HBWR. After that the storage facilities at the sites will be emptied and decommissioned. Successively the Metlab 2 and finally the Waste treatment building and offices will be dismantled.

When all buildings are emptied, walls and floor surfaces are decontaminated and the building material is cleared from regulatory requirements, the buildings are demolished and taken care of. Finally, the site area is cleared from regulatory control and thus released from its concession as a nuclear facility.

The time planning and work packages are still to be further defined.

3.3 Regulatory approvals/milestones

Before proceeding with work that might cause risk or spread of radioactive material, regulatory approval is needed to ensure that plans, safety assessments and possible risks for each work are appropriately handled. Decommissioning and waste handling requires authority approvals in many steps and at different occasions such as:

- Start of decommissioning
- A notice is sent at start of each new work package
- A report is sent at each finalization of a work package
- Clearance of material
- Clearance of land

Design, construction and commissioning of new facilities need several regulatory approvals, at least:

- Siting
- Concept design
- Basic design
- Commissioning

4. NND Waste management roadmap [2]

As the IFE nuclear facilities are taken out of use and the decommissioning phase starts, a large part of their contents are redefined as waste. [22] Waste can be divided into radioactive waste and conventional waste with regards to the Pollution control act [7] and its Regulations on radioactive pollution and radioactive waste. [11] To separate radioactive waste from conventional waste, all waste must go through a clearance process approved by the authorities, this is further discussed in chapter 4.7.

4.1 Waste management phases

The required space and infrastructure for waste treatment is dependent on the pace of the decommissioning. The higher the pace, the more capacity and infrastructure is required. With regards to existing infrastructure and the foreseen possibilities to license further facilities, the waste management can be divided into four different phases depending on which facilities are available. Before new facilities are in place, the best possible use must be made of current facilities and possible modifications of them.

The planned RWM can, as discussed in chapter 7, be divided into four different phases:

1.) Present Operation (Transition) phase (ch. 7.1)
2.) Start of decommissioning phase (after commissioning of some additional facilities on existing sites, and received permission for decommissioning) (ch. 7.2)
3.) Later decommissioning phase (after Interim storage facility is commissioned) (ch. 7.3)
4.) Disposal phase (after National disposal facility is commissioned) (ch. 7.4)

This document describes the planned facilities (ch. 7) and needed containers (ch. 8) for management (ch. 6) of radioactive waste, from receival to disposal with a focus on phases 2 and 3.

4.2 Waste hierarchy

The waste hierarchy is a binding principle in the EEA Waste Framework Directive [26], which also states that this shall form the basis of member states' waste policies. Norway is obliged to this through the EEA Agreement. The waste hierarchy has been a guiding principle of Norwegian waste policy for many years. Environmental or other considerations may give grounds for deviating from the waste hierarchy for specific waste streams when justified on the basis of a life cycle approach, cf. Article 4(2) first paragraph of the Waste Framework Directive.

[2] NND Waste management strategy [2] is given in the NND management system. This chapter is a further elaboration and concretization of the fundamental headlines given in the strategy document.

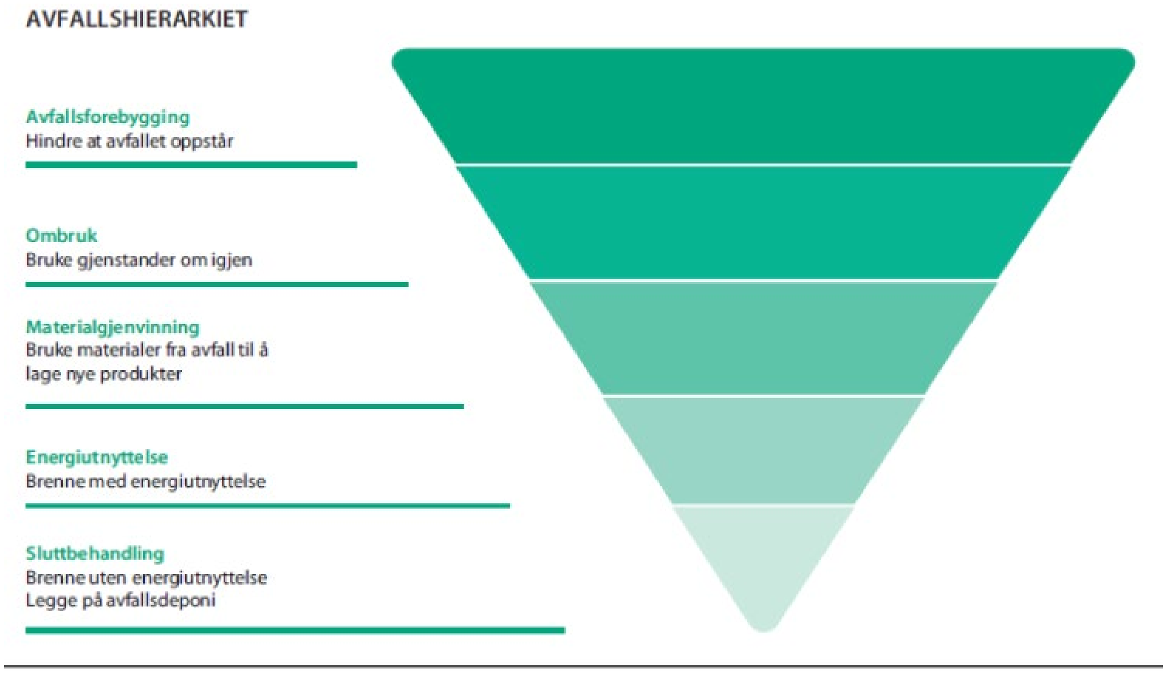

Figure 2: The waste hierarchy – the ambition of lowering waste amounts and make the most possible use out of actual waste arisings [2] [27] [28]

In general, for waste that has already arisen, reuse should be given the highest priority, then material recycling should be prioritized over incineration with energy utilization. Combustion without energy utilization and disposal shall be the last choice. The choice of disposal method must nevertheless be assessed in relation to the type of waste. For example, it will not be desirable to recycle waste types that are harmful to health or the environment.

4.3 Radioactive waste management fundamentals

4.3.1. Activation

The activity in nuclear waste can principally be of two different kinds – activation and contamination. Activation relates to material that has been exposed to direct neutron radiation and thus has a changed material composition more or less right through the material. The addition of neutrons has thus changed the original distribution of isotopes and/or elements . Activated material is thereby present only in material exposed to neutron radiation from the reactor core or fuel storages, i.e., typically the reactor tank, reactor tank internals, biological shield, fuel storage lining and fuel storage concrete.

As activation has changed the material composition, the material cannot be cleaned and thus must be disposed of.

4.3.2. Contamination

Contamination is adhesion of active particles to the surface of different materials. As the added activity is only adhered to the surface of the material, it allows for different kinds of surface treatment to remove it so that the material can be recycled. The adhesion can be in many forms: from dust from the reactor hall atmosphere to heavily adhered burned oxide layers generated in hot process systems.

Consequently, some contamination can easily be removed by wiping, while others may require heavy machining. Decommissioning and waste handling must be planned carefully so as not to spread loose active particles, causing cross-contamination.

4.3.3. Scaling factor

Depending on position in the plant the material has been exposed to different kind of contamination or activation and thus has a specific relation between the amount of different nuclides. For example, activated steel or concrete will have a very different nuclide distribution than a filter containing particles from a failed fuel rod. If it is shown that the radionuclide distribution is homogeneous, it is only necessary to measure the concentration of one nuclide and then calculate the concentrations of the others using the known relative amounts, using so-called scaling factors (or nuclide vectors). This is especially useful in cases where some of the other nuclides might be difficult to measure (DTM) nuclides.

As part of the categorization this relation have to be examined in a number of different positions in the plant. The facilities have to be divided into a certain number of systems or areas that can be considered to have the same relation between the different radioactive nuclides. After that a key nuclide is measured and the presence and amount of associated nuclides can be calculated. This is further explained in [29] and [30].

4.3.4. Short lived / Long lived waste

Radioactive waste is managed according to the half-lives of the isotopes present. The waste is therefore divided into very short lived waste, short lived waste and long lived waste.

Very short lived waste (VSLW) has a half-life up to approximately 100 days, which means after a few years the activity is practically gone. In the case of IFE’s reactors, a period of more than ten half-lives has already elapsed, and these isotopes are to all extents no longer present. This waste class is thereby not considered further in this report.

Short lived waste (SLW) is generally defined as containing isotopes with half lives up to 31 years. The category thus includes the important isotope Cs-137. SLW typically consists of activated and contaminated metal and concrete, which constitute the bulk of general RW. This category of waste is the most important when planning dose budgets and personnel safety etc. for decommissioning and waste management.

Long lived waste (LLW) has a half-life from 31 years up to billions of years. Significant amounts of these nuclides are present in spent nuclear fuel and material that has been in contact it. This type of waste is the most important when planning long term geological disposal.

4.4 Precautions for limiting the amounts of radioactive waste

The amount of radioactive waste should as far as practically possible be minimized. [31] [32] This is also the highest step in the waste hierarchy triangle.

The project will apply branch standard restrictions regarding adding more waste e.g. through stripping incoming deliveries of packaging before entering the site. The project will also evaluate every addition of secondary waste such as water, blaster sand, plastic sheets and other commonly used consumables within the decontamination and decommissioning.

Another way of limiting the amounts of RW is through sorting out non-radioactive material, i.e., clearance, see ch. 4.7. As part of the POCO an evaluation should be made regarding which material can be reused. It may be possible to send some material, e.g., fresh fuel, fresh IER, heavy water, spare parts etc. as resources to other facilities. Later on, during decommissioning transformers, diesel motors and electric motors etc. can also probably be cleared for reuse.

4.5 Categorization of waste

4.5.1. General

Waste will be sorted with regards to material composition, handling risks, radionuclide distribution and scaling factor, in line with, e.g., requirement 8.37 in [32]. Different materials will be segregated at the dismantling stage .

4.5.2. Waste categories

Waste categories are handled in FLYT. A complete list of material categories is given in attachment 1. Components are also listed with regards to their "Asset type", the list of asset types is given in attachment 2.

Examples of material categories are:

- Concrete
- Soil
- Carbon steel
- Stainless steel
- Lead
- Copper
- Hazardous material

The main part of the decommissioning waste is non-radioactive concrete. Other large fractions are carbon steel, stainless steel and soil.

4.5.3. Risk categories

Certain materials are defined as environmentally harmful. Examples are asbestos, lead and cables. This type of material is handled separately according to conventional regulatory guidelines.

Concrete from each building/batch should be analyzed with regards to its contents, e.g., old concrete might contain hexavalent chromium, Cr(VI), which is both toxic and carcinogenic.

A special type is hazardous waste combined with radioactive contamination which has to be treated with regards to both limitations.

4.5.4. Waste acceptance criteria (WAC)

Waste acceptance criteria (WAC) are quantitative or qualitative criteria specified by the regulatory body, or specified by an operator and approved by the regulatory body, for the waste form and waste package to be accepted by the operator of a waste management facility. WAC specify the radiological, mechanical, physical, chemical, and biological characteristics of waste packages and unpackaged waste. They may include, for example, restrictions on the activity concentration or total activity of particular radionuclides (or types of radionuclide) in the waste, on their heat output or on the properties of the waste form or of the waste package. Waste acceptance criteria are based on the safety case for the facility or are included in the safety case as part of the operational limits and conditions and controls.

Requirements for WAC is also given in IAEA GSR part 5, e.g.:

> ***Requirement 12: Radioactive waste acceptance criteria***
>
> *Waste packages and unpackaged waste that are accepted for processing, storage and/or disposal shall conform to criteria that are consistent with the safety case.* [22]

For treatment, transportation and storage the requirements handle mainly working environment and personnel safety, whereas, for waste disposal more long term matters, e.g. durability and non-solubility are more important. Also the most important nuclides will vary through the lifecycle of the waste. For transportation and storage, relatively short-lived nuclides such as Co-60 are the most important, whereas for disposal more long-lived nuclides such as Cl-36 become the controlling nuclides.

WAC also put requirements on chemical and toxic materials, e.g., for disposal facilities substances are excluded that can cause deterioration of the metal or concrete containment used as a barrier to shield hazardous material from reaching the environment.

With regards to these differences, packaging and conditioning should be chosen with regard to the entire lifecycle of the waste, in order to avoid unnecessary handling operations.

4.6 Waste classification

Radioactive waste is classified with regards to its activity content and the half-lives of the radionuclides. Fundamentals for classification of nuclear waste are given in IAEA report GSG-1. [33] Waste classes are further discussed in relation to the Norwegian context in, e.g., [17].

A study will be made to define areas/systems with different type of contamination, causing different scaling factors to be used in the waste classification.

4.6.1. Exempt waste (EW)

Exempt waste is by definition non-radioactive waste, i.e., waste that can be cleared from regulatory control due to its very low level of radioactive substances. In Norway this is defined in the Ministry of Environment’s “Regulations on radioactive pollution and radioactive waste” [11]. The removal of regulatory control from the sorted out non-radioactive material is known as clearance of material.

DSA specify the importance of segregating radioactive waste from conventional, exempt, waste.:

> *“Sorting radioactive waste from non-radioactive wastes will be particularly relevant in connection with the decommissioning of the research reactors at IFE and the decommissioning of facilities for the production of radiopharmaceuticals and proton*

> *therapy. Here, it is important that radioactive waste is sorted from non-radioactive waste in order to minimize the amount of radioactive waste."* [34]

After clearance, the material can be handled as conventional waste. Structural steel and piping etc. can then be sold to a conventional metal recycling company. Other waste should be packed into containers and sent for recycling at the closest waste station. Emptied containers should be returned and reused.

The process for clearance of waste is further described in chapter 4.7.

4.6.2. Very Low-level Waste (VLLW)

Very low level waste coincides closely to what in Norwegian legislation is defined as "RW without disposal obligation" – i.e. RW not strictly bound for disposal [11] [17]. This waste is generally used in such a way it does not affect humans or the environment in a significant way. The first choice to be examined should be to use it as filling material after the decommissioned buildings at the nuclear sites.

Other possible choices for this type of material are to use it in road or rail construction where it would not come into close contact with humans and where its low activity will not adversely impact on people and the environment.

It can also be disposed of in a dedicated or commercial landfill facility, for decay during several decades after which the specific activity will be low enough for unconditional clearance. It should be evaluated if a disposal of this kind should be arranged at the interim storage site after a site location has been chosen.

4.6.3. Low level waste (LLW)

LLW ranges from radioactive waste with an activity content level just above that for VLLW, that is, not requiring shielding or particularly robust containment and isolation, to radioactive waste with a level of activity concentration such that shielding, more robust containment and isolation are necessary for periods up to several hundred years. Sometimes a contact dose rate of 2 mSv/h is used to distinguish between LLW and the next category, intermediate level waste (ILW), however the long term environmental impacts should be of larger importance to this division.

In the Norwegian legislation, LLW together with ILW is called "RW with disposal obligation". It must be collected and taken care of. Authorized personnel should handle the waste according to given processes in order to avoid unnecessary radiation exposure. Generally, the waste is put in boxes or containers which are stored in the interim storage before transport to disposal.

4.6.4. Intermediate level waste (ILW)

Radioactive waste that requires shielding but needs little or no provision for heat dissipation is classified as intermediate level waste. Human exposure should be avoided, if possible the treatment should be handled by robot or in a hotcell or compartment, otherwise only well planned and quick measures could be done by human hand. The waste is stored and transported in well-shielded, thick and heavy casks, molds or canisters.

4.6.5. High level waste (HLW)

The general definition of HLW is that it requires containment and isolation on another level than ILW. Another characteristic is that it generates significant levels of heat. This is not the case in the Norwegian radwaste where not even the spent nuclear fuel (SNF) requires special measures for cooling in today's storages. The requirements for containment and isolation of HLW over long periods necessitate deep geological disposal.

4.6.6. Long lived waste

Long lived waste is waste with significant amounts of nuclides with a half-life of more than 31 years. These nuclides include many of those present in fresh and spent fuel. Long lived waste thus also includes components that have been contaminated during fuel fabrication or after a fuel rod is damaged.

Long lived waste thus has significant similarities to spent fuel, and requires similar management, i.e., it is stored and transported in casks certified for nuclear fuel and requires geological disposal.

4.7 Clearance of material

When decommissioning a NPP the dismantled material will be a mix of highly radioactive material and e.g. furniture that have a very low level of radioactivity. To manage this, i.e. not to put unnecessary efforts on very low radioactive material there are certain radiation levels worked out to separate radioactive material from "non-radioactive material". Thereby it is possible to sort out "exempt waste", as mentioned in chapter 4.6.1. The definition of "non-radioactive" is set in "The regulations on radioactive pollution and radioactive waste" [11] with regards to specific activity levels for each nuclide in the material, see figure 1 in chapter 2.1.

This process is internationally known as clearance of material. In order to appoint certain waste as non-radioactive, the waste or the building must pass a clearance process. This means the material will be cut down to pieces fit for a Berglöfslåda [24] or similar size box, which will be measured in a clearance facility according to given procedure. Buildings and large components can be cleared as they are according to special procedures, without first being cut down.

For clearance each nuclide should be measured or calculated and put in relation to its allowed amounts given in the regulation. The percentages for the different nuclides are then added and should not reach more than 100% in total. As an example, if the key nuclide Co-60 reaches 60% of its allowed value, then the sum of all other radioactive nuclides can only reach 40% of their respective allowed values according to [11].

To manage this clearance process, the waste is measured in a facility such as shown in figure 3.

Figure 3: Picture of the RTM661-440 clearance monitor from Mirion Technologies [35]

Clearance is also divided into two different categories depending on the level of radioactivity in the material: conditional clearance and unconditional clearance. Unconditional clearance means that after clearance the material can be handled as conventional waste. Conditional clearance means that material under certain conditions can be cleared up to a slightly higher level of radioactivity, i.e. the material can be reused only if it can be shown that the material will be used in such a way that it won't cause harm to people or the environment.[3] These two different levels are shown for different nuclides in figure 1.

Due to current law there is however a set of paragraphs[4] requiring a special license for all handling of material that has become radioactive through operations related to production or use of nuclear fuel. As there is no lower dose or activity limit to this requirement, it practically voids the regulation regarding clearance. This must be changed before an uprate of waste flow is possible. Work regarding exception from this law, for material possible to clear according to [11], is ongoing.

4.8 Methodology and Best available technique (BAT)

A hallmark for the nuclear power business is its steady focus on safety. A strict compliance with safety culture is emphasized in the regulatory requirements for a license holder. Used methods and techniques should thereby be thoroughly evaluated and follow the highest standards. Before entering the decommissioning phase, fuel is removed, and the nuclear safety risks thus drastically lowered. Nevertheless, focus on safety should be kept high also during waste treatment. Thus, it is important to make sure using a proven methodology and BAT for each respective working field.

[3] In the Norwegian regulation the division is formulated as where the non-cleared material is with or without a disposal obligation, which in principle has the same meaning.

[4] The nuclear energy act §§ 1b, 1c & 5.1 [8]

Methods should be proven scientific and undergo verification & validation procedures according to the principles in ISO 9001 chapter 8 in order to reach certain level of quality assurance before being used. Recently innovated methods, non-proven techniques and tools should not be used. [2] [36]

Verification of the waste characteristics and waste packages should be based on procedures that typically include direct measurements on the material, laboratory measurements of representative samples, the use of properly derived radionuclide vectors (e.g. scaling factors, and correlations between difficult to measure radionuclides and easy to measure radionuclides) and adequate identification of the waste origin. [32]

Decommissioning and waste treatment should be well documented, and information should be retrievable from a document management system. The document system should contain all investigations and decisions made, in order to be able to trace decisions and enhance accountability. Documents should be dated, numbered and have a revision number, and should at a minimum be signed by the author, reviewer and approver. They should be retrievable, and it should be clearly stated if a document is valid or not.

Knowledge from experience of decommissioning of other nuclear plants should be used through international experience exchange. Internationally acknowledged classification and storage principals should be implemented. Contractors are chosen to fulfil typical quality criteria such as ISO 9001/10006/14001 or similar. Purchase qualification criteria as defined in NNDs general procedures for purchases must be adhered to.

Decommissioning and waste treatment should be structured, and requirement based. Waste is tracked through the process with the waste treatment tool FLYT.

Work packages are planned to limit cross-contamination, to enable interoperability between different contractors and to enhance predictability of the assignment to different waste streams to support planning of the waste facilities and infrastructure for the waste flow. Thus, each work package must have a clear scope and well defined interfaces to other work packages.

5. Waste inventory

Today's waste handling is done primarily at the Radwaste facility at Kjeller, which handles waste that originates from a number of different waste producers, including:

- Industry (for example sealed radioactive sources)
- Consumer products (for example smoke detectors)
- Hospitals
- Research activities (universities)
- Military
- Waste generated by the operation of IFE’s nuclear facilities
- Decommissioning of IFE’s nuclear facilities

An estimation of the amounts of waste has been done by Studsvik and reported in the MOA report. [37] These estimations are in large parts very rough. They therefore have to be confirmed through a physical- and radiologic characterization of the waste. Work regarding this characterization is started but results are not foreseen within at least a year. Waste amounts given in this report should thus be seen as unsure and a new edition of the WMP should be written when amounts from the characterization have been implemented.

The total waste flow handled at Radavfall in Kjeller today is around 120-180 barrels per year.

In the MOA-report the waste is divided into the following categories:

- IFE operational waste
- IFE legacy waste
- IFE decommissioning waste
- National waste arisings

As can be seen in the following diagram the decommissioning waste is dominant, accounting for 97 per cent of the total.

Figure 4: Total waste arisings (in tons and percentage)

The amount of waste given includes both radioactive waste and non-radioactive waste, in the latter the non-radioactive concrete handled in the demolition phase is dominant.

5.1 Spent nuclear fuel (SNF)

The spent nuclear fuel originates from the operation of four research reactors at Kjeller and Halden sites between 1951 and 2019 [38].

- JEEP I (Kjeller)
- JEEP II (Kjeller)
- NORA (Kjeller)
- HBWR (Halden)

SNF from the operations of the research reactors at Kjeller and Halden is currently stored in various storage facilities at the sites. The inventory of SNF is listed in table 2.

Table 1: Inventory of spent nuclear fuel stored at Kjeller and Halden [39].

Designation	Fuel material	Cladding material	Irradiated in (reactor)	Enrichment, %	Amount, tons
JEEP I* / HBWR 1st charge	Metallic uranium	Aluminium	JEEP I, HBWR	0,72	10
JEEP II	UO_2	Aluminium	JEEP II	3,5	1,5
HBWR driver	UO_2	Zircaloy	HBWR	≤ 10	3,6
HBWR booster and experimental	UO_2, MOX, ThO_2 + various	Zircaloy plus various	HBWR	≤ 20	1,4

The SNF consists of fuel assemblies and individual fuel rods. Some rods are whole while others have been sectioned for Post-irradiation examination PIE. Some of the rods are damaged or failed. The inventory is characterised by a large variation in fuel and clad materials, dimensions, enrichment and burn-up.

Together with the SNF there is a significant amount of other long-lived waste which is today placed in fuel assemblies and stored in the fuel storages. This material has to be further categorized but is for now handled as legacy waste in chapter 5.3.

There is also an amount of highly enriched Uranium/Thorium (HEU-TH) which has to be taken care of, which is further discussed in chapter 6.2.4.3.

5.2 IFE Operational waste

Operational waste includes clothing, cloths, filters, tools, water, liquids and spent ion exchange resin (IER). An estimation of amounts is made in the MOA-report [37] and shows the following results:

Figure 5: Operational waste (in tons)

5.3 IFE Legacy waste

Legacy waste consists of soil, liquids and disused parts from the nuclear facilities. The composition is in some cases unknown but it generally contains long-lived waste.

In Kjeller the legacy waste consists to a large part (40 tons) of liquid/sludge, while around 24 tons is solid material such as components and material from fuel fabrication.

Data from Halden shows there is approximately 20 tons of fuel assemblies without fuel but filled with other contents such as minor components or parts of components from fuel tests etc. There are also 20 tons of contaminated fuel pit lining and 20 tons of components, where fuel transport utilities are half and lead shielding from a tomograph is the other half. The material is generally assumed to be both activated and contaminated, and thus not eligible for clearance.

Among the legacy waste is also 166 drums (39,8 tons) of plutonium-contaminated soil which is now placed in storage at KLDRA. According to the MOA-report (table 155) half of this can be conditionally cleared while the other half should be processed as VLLW.

5.4 IFE Decommissioning waste

During the future decommissioning of the Halden and Kjeller sites, relatively large quantities of radioactive waste will be generated. The larger waste quantities will require significant upgrading of treatment facilities.

An estimation of the amounts of decommissioning waste amounts has been made within the MOA-project. [37]

Table 2: Total estimated waste amounts from the decommissioning of the IFE-NUK facilities

	Total RWM route									
Waste Type/ Sub-Type	Unknown [Ton]	Uncond. Clear [Ton]	Cond. Clear [Ton]	Easy To Deconta-minate [Ton]	Process as VLLW [Ton]	Process as LLW (New) [Ton]	Process as ILW (New) [Ton]	Process for RWM by ESP [Ton]	Treatment of Active Effluents [Ton]	Total [Ton]
Components	59,3	74,6	137,6	38,8	0,0	519,6	413,3	64,8	0,0	1 308,0
Piping	0,0	50,5	8,9	5,3	0,0	20,1	14,2	4,2	0,0	103,1
Structural Steel	0,0	227,1	245,9	15,7	0,0	56,9	0,2	2,0	0,0	547,7
Ventilation	0,0	36,0	10,6	25,6	0,0	32,3	6,3	3,2	0,0	114,0
Cabling & Chutes	0,0	18,2	210,6	2,4	0,0	52,8	0,5	0,5	0,0	285,0
Reinforcement	0,0	857,7	139,1	0,0	0,0	12,0	30,9	0,0	0,0	1 039,7
Concrete	151,0	36 215,3	1 253,9	0,0	1 253,9	577,4	374,2	0,0	0,0	39 825,6
Soil	0,0	0,0	0,0	0,0	1 295,2	0,0	0,0	0,0	0,0	1 295,2
Combustibles	0,0	28,2	125,3	0,0	0,0	17,4	0,0	4,4	0,0	175,3
Insulation	0,0	2,5	10,0	0,0	0,0	0,0	0,0	0,0	0,0	12,5
Heavy Water	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	25,2	25,2
Resin	0,0	2,0	0,0	0,0	0,0	0,0	0,0	7,2	0,0	9,2
Liquids	0,0	0,0	0,0	0,0	0,0	0,0	0,0	17,3	69,4	86,7
Other	0,0	7,6	0,1	80,0	0,0	168,9	24,0	28,2	0,0	308,8
Total:	**210,3**	**37 519,7**	**2 142,0**	**167,7**	**2 549,1**	**1 457,4**	**863,5**	**131,7**	**94,6**	**45 136,0**

The table shows that the major part of the decommissioning waste consists of non-contaminated concrete from the demolition of the facilities.

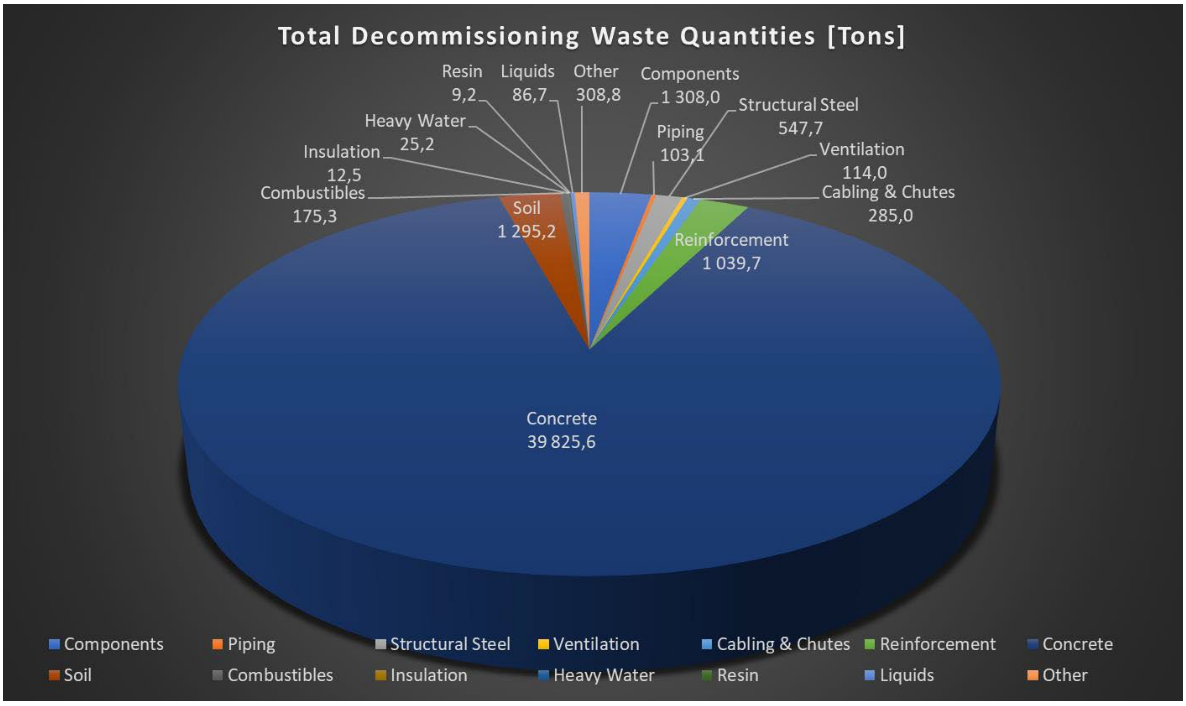

Figure 6: Decommissioning waste from the IFE facilities (in tons)

5.5 National waste arisings

National waste arisings consist of industrial waste as well as research and societal waste, where waste from research is the predominant part.

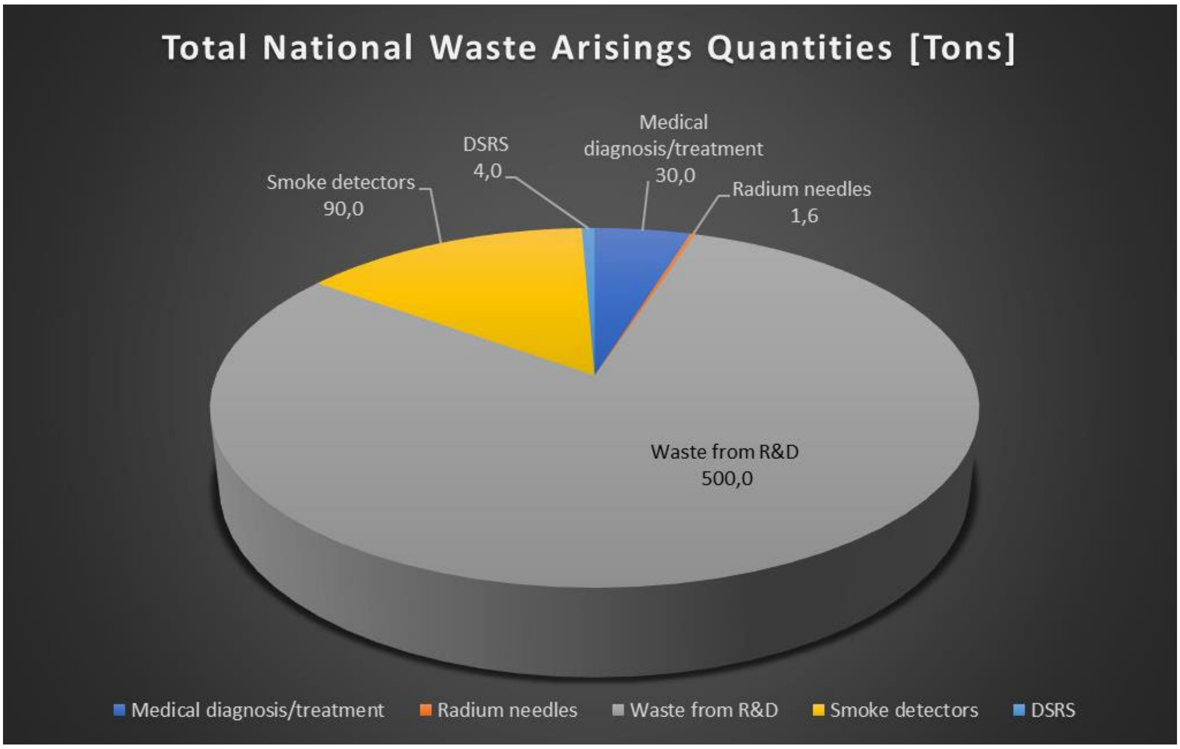

Figure 7: National waste arisings (in tons)

Large part of societal radioactive waste is used fire alarms, which have a radioactive source containing Am-241. The annual inflow of used fire alarms in Norway is slightly above 10 tons.

After alarms are received, they are dismantled and the plastic cover is recycled as conventional waste, whereas the Am-241 source and circuit board are taken care of and handled as long-lived radioactive waste. Am-241 has a half-life of 432 years.

6. NND Waste treatment methods / Waste streams

This chapter describes the flow of radioactive waste through the waste management system.

When receiving waste from decommissioning contractors or external suppliers, the waste package must be labelled with its contents and origin. Accuracy of this labelling shall be evaluated at reception.

As there are many different sources and types of waste, a common handling process may be hard to follow, thus a high degree of non-standardized waste handling is likely to be used. A generalized description is therefore not sufficient to fully describe the activities related to each type of waste. Therefore, a general process is described in chapter 6.1 while chapter 6.2 breaks down the process in a more specific manner for each waste type.

6.1 General waste management process

The process for management of radioactive waste can to a certain degree be generalized for all waste types. The different waste streams do in most cases have a similar process in terms of transport, storage, and disposal. The differences between the waste streams lie for the most part within the treatment methods and the type of waste containers used.

As described in chapter 4.1, the process will also change with regards to which waste management phase is valid. This chapter describes this generalized process (illustrated in Figure 8), in a physical and administrative perspective.

External radioactive waste is received at Kjeller (Radwaste facility) and, in the future, at the interim storage facilities to be constructed. The Halden site does not receive any external waste and thus handles only internal waste. Waste is received, either externally from society or internally from operation or dismantling of the nuclear sites, by that time it should already be labeled with waste category and waste class. It is then transported, either to a buffer storage for cleared material, or to the treatment facilities in either Kjeller or Halden for treatment and storage. When the interim storage facility is in place, the waste will be transferred there for continued storage. Waste that does not fulfill the WAC for a given treatment point or storage will have to be repacked or re-destinated.

A simplified overview of the waste process is given in the figure below.

Tilgjengelig for offentligheten

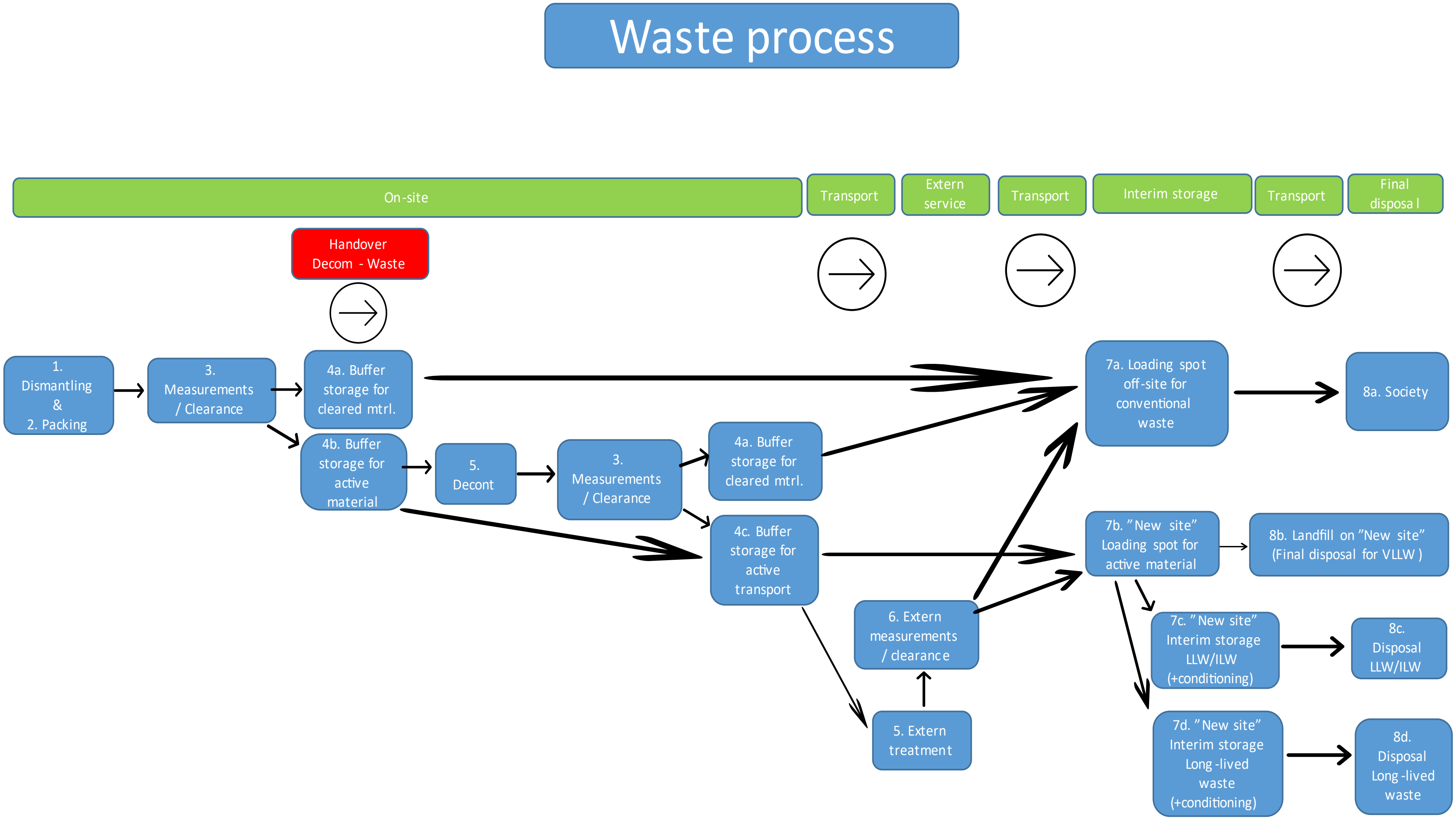

Figure 8. General process for the flow of VLLW-ILW.

6.2 Specific waste streams

In this chapter, the general waste stream is divided into specific waste streams based on waste properties. This gives the foundation for gaining a more detailed overview of the required capacity of certain treatment- and storage facilities to handle different types of waste streams and their respective volumes over given time periods, both currently and in the future.

Upon reception of waste, the appropriate waste stream and treatment route will be selected, based on its characteristics, for example, material, geometry, specific activity, and type of contamination.

The purpose of the different waste streams is to raise as much material as possible in the waste hierarchy triangle given in chapter 4.2, thus increasing the level of recycling. Expert judgement will be used to evaluate whether waste can be cleared through relatively simple treatment. If not, then the extra dose to personnel and other costs will not be worthwhile, and the material will not undergo treatment.

Figure 9 illustrates a division into the different waste streams and the different treatment stations and storages necessary for this handling. The waste streams presented include those waste types that the waste management system is designed to manage on a regular basis. Other waste types not included in the categories below will be handled on a case by case basis as they occur.

Waste acceptance criteria for the future disposal facilities have not yet been defined as the disposal concepts are not finalized. NND plan to develop preliminary WAC based on international practice, although it is recognized that these may need to be modified. Thus, the final conditioning of waste will be done at a later stage according to the regulations and WAC valid at the time of disposal.

Tilgjengelig for offentligheten

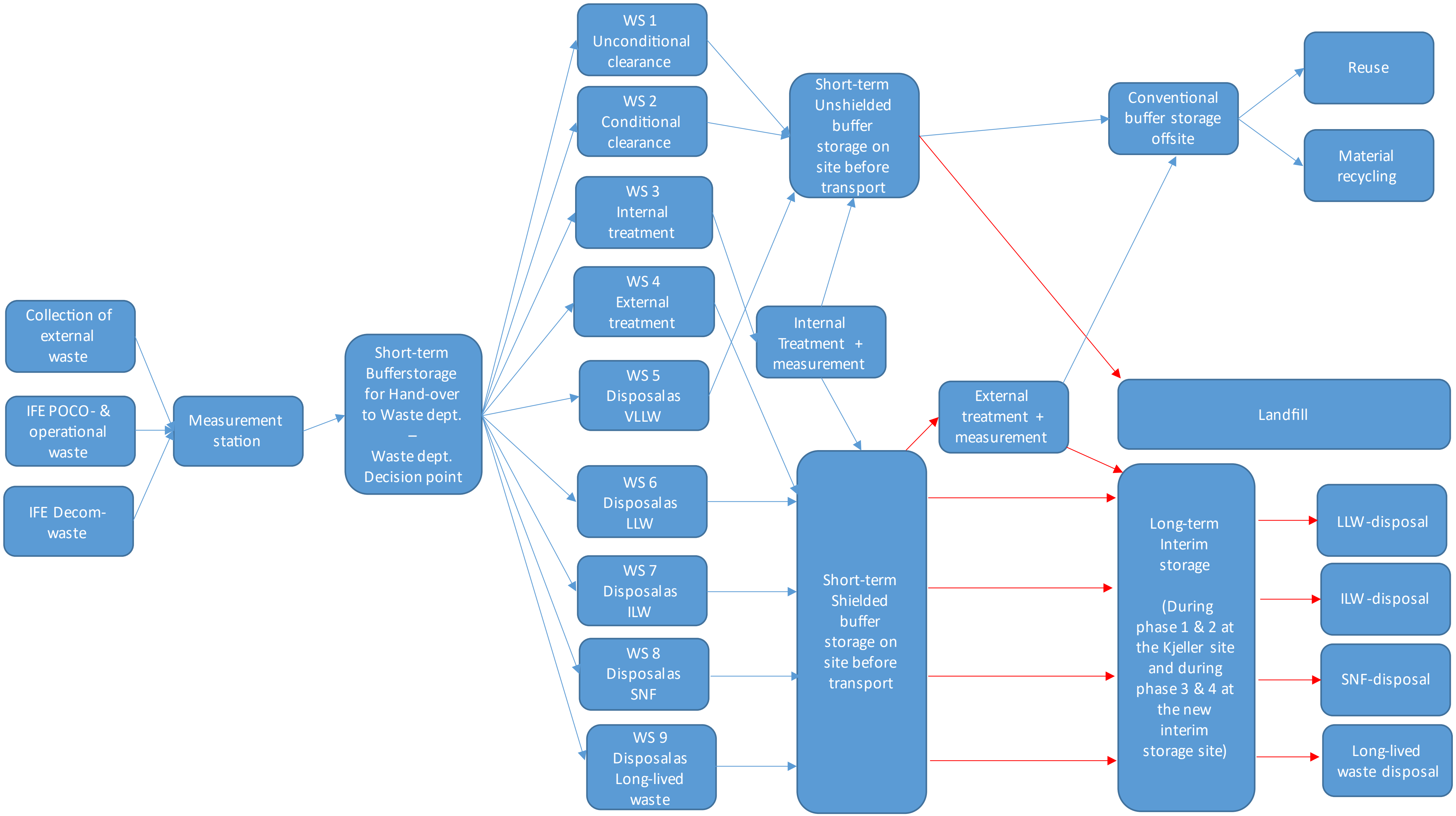

Figure 9: Illustration of the different waste streams (red arrows indicate external RW transports

6.2.1. WS1 – Unconditional Clearance

Unconditional clearance is made with regards to specific clearance levels given in [11]. Scaling factors are determined with regards to methods given in [29] and [30], and explained in chapter 4.7.

Amount

According to the values given in chapter 5, at least 80% of the total waste is non-radioactive and can thus pass unconditional clearance. According to the quantification there is a total of 40 kton concrete and 1 kton reinforcement steel to be handled in the project. With the assumption that 90% of this will be left for the final conventional demolition, it follows that 10% is handled during main phase of the dismantling. This means that up to 4000 tons concrete and 100 tons reinforcement steel should be directed through clearance during the dismantling phase. This equals 200 well-packed standard half-height 20-foot containers. This will be the dominating material directed for clearance.

Treatment

Material in this category is fit for unconditional clearance and thus does not need further treatment other than compacting for enhanced handling. Material from other waste streams might after treatment also be fit for unconditional clearance.

After dismantling or reception, the waste containers are taken to a clearance measurement facility. The key nuclide is measured and combined with the scaling factor to determine whether the material can be cleared.

Storage

Cleared material is placed in a buffer storage waiting for further transport to an offsite storage space for conventional waste before it’s passed on out in the society, preferably for reuse or material recycling according to the waste hierarchy given in chapter 4.2.

10 % of the concrete and reinforcement steel will be handled during the dismantling phase, at year 1 to 15 of the decommissioning. Unconditionally cleared waste is passed out to society for recycling in batches at least twice a year, which means there will be a temporary storage requirement of up to 10 standard half height 20-foot containers in total.

90 % of the concrete and reinforcement steel will be handled during the demolition phase, at year 15 to 17 of the decommissioning. In case this unconditionally cleared waste is passed out in society continually with a temporary storage requirement of two weeks, there will be a need for storage capacity of up to 15 standard half height 20-foot containers in total during these years.

Disposal

Not applicable.

6.2.2. WS2 – Conditional Clearance

Conditional clearance is made with regards to specific clearance levels given in [11].

Amount

This waste stream contains 1800 tons of material[5] which equals 4% of the total decommissioning waste amount. The main parts are concrete (1250 tons), structural steel (250 tons), components (140 tons) and reinforcement steel (140 tons).

150 tons concrete and 60 tons components are allocated to the category with unknown activity. This material will be measured after dismantling and handled via the relevant waste streams. As these waste streams are considerably larger, they are considered to be able to handle this extra amount.

Treatment

Conditional clearance is feasible when specific use of the slightly contaminated material is approved. This can be used specifically for soil and for slightly contaminated concrete that, for example, can be used as filling material after removal of the IFE-NUK facilities.

Storage

The material should be sent to a conventional storage, or in due time to the NND's interim storage and kept in a separate building, from where it can be delivered out in the society in a regulated manner. Concrete should in firsthand be used for filling up the pits after demolition of the buildings in Halden and Kjeller. Second hand it can be used in societal construction works such as roads, railroads etc. Metal should be sent for melting in Cyclife or similar facility with experience of active material. The molten and recycled material should be used in societal construction works where the anticipated dose to persons is lower than if the metal was sold to the general metal market. This is due to that human exposure for the material is limited. However an EIA has to be made in each specific case to evaluate dissolution of particles through ground water flows etc.

Disposal

Not applicable

6.2.3. WS3 – Internal treatment

The nuclear facilities in Halden and Kjeller will be equipped with treatment stations with equipment for decontamination, solidification of liquids and compacting of compressible material. This will in firsthand be done at the nuclear sites but will later on be moved to the new site as dismantling of the facilities progresses.

[5] Excluding the 210 tons of cables and 125 tons of combustible material, both handled in chapter 6.2.4.1, and excluding the 10 tons of insulation discussed in chapter 6.3.2

Amount

This waste stream consists of e.g. structural steel and contains 170 tons of material, which equals 4 ‰ of the total decommissioning waste amount. In addition, certain material that is relatively thick with loose contamination, such as, for example, the shell of the Halden steam drum, steam generators, steam transformers and delay tanks, could be routed for surface treatment in special blasting facilities within the respective plant.

Treatment

Different types of material require different treatment, see subchapter 6.2.3.1 to 6.2.3.4

Interim storage

After treatment, the main part of the liquids should be able to pass clearance and thus be disposed with the sewage. The removed particles are collected in filters, IER or evaporation resins, measured and, together with the secondary waste, routed to WS6 – LLW.

After treatment, the main part of the solid material should be able to pass clearance. The removed surface contamination is collected, measured and, together with the secondary waste, routed to WS6 – LLW.

Disposal

The radioactive part of the waste is handled with regards to its measured content of specific activity, most probably as LLW and thereby routed to WS6.

6.2.3.1. WS3a – Segregation

For some types of waste, it is obvious which parts are active. For example, fire alarms have a radiation emitter containing Am-241. In this case the emitter is manually separated from the plastic cover and the battery.

Segregation can also handle the separation of the uncontaminated valve actuator from a contaminated valve, or separation of a clean electric motor from a contaminated pump. In these cases, the segregation is done through unscrewing of attached parts. Segregation can also handle separation of other types of clean material from contaminated components, e.g., a tank or a heat exchanger can be partly contaminated. In these cases, separation can be done through cutting of larger metallic components in a workshop if surface treatment is not feasible.

6.2.3.2. WS3b – Decontamination before Clearance (ETD)

Decontamination means to remediate the surface of a material in order to remove adsorbed nuclides/particles. The simplest decontamination is cleaning with a cloth, with or without addition of alcohol or detergents.

Another method is water blasting. With high water pressure, loose particles and oxides can be removed from the material. However, this puts requirements on the water treatment facility and recycling of water etc. Addition of the water as secondary waste must be evaluated since contaminated water has to be taken care of.

A third method is blasting with either sand, metal particles or particles such as frozen CO_2 etc. As in previous case with water, the addition of secondary waste has to be evaluated, together with the risk of causing air-borne activity.

Mechanical treatment can also be used to separate contaminated material from clean material. This can be done in an ordinary metal workshop. Preferably cold cutting methods should be used so as to not cause release of air-borne particles and to not cause further adhesion of active particles to the heated material.

However, the MOA-report [37] recommends (on p.22) that aggressive decontamination techniques should not be pursued since it is unlikely that the benefits of such techniques will exceed their disadvantages, particularly the generation of secondary waste and the potential risks to operating personnel. Decontamination should therefore be assessed on a case by case basis, investigating how tightly the contamination is attached to the material, and whether sand blasting, water blasting, or other types of remediation are feasible and appropriate.

6.2.3.3. WS3c – Treatment of active liquids

Water based liquids should be run through the water treatment facility where radioactive particles can be separated onto filters or ion exchange resins (IER). After passing this facility, the activity should be measured and chemical composition evaluated. Liquids fulfilling given criteria can be poured to the sewage and other liquids should be further treated or deposited according to chemical/radioactive regulations. This can be managed through e.g. incineration, evaporation or solidification. The chosen method will depend on the properties of the liquid and the form of the radioactive material. Evaporation has the advantage that the volume is significantly lowered. The steam content is filtered and checked, and the remains are measured and taken care of.

Oil and alcohol-based liquids should be evaluated due to its content and primarily sent for incineration. Hazardous liquids should be taken care of with regards to radioactive- and conventional chemical regulations.

Remaining liquids are to be stored and deposited. To eliminate risk of leakage, active liquids are preferably converted to solid waste. Solidification is generally handled by simply adding cement. Activity is then bound to the concrete which will hinder solubility and attenuate its radiation causing lower dose to personnel and surroundings.

6.2.3.4. WS3d – Compaction

Compaction of metal and concrete should generally be handled by the dismantling/demolition contractor before handing over to the waste team. However, there will be occasions when further compaction is needed. Therefore, a metal workshop is needed to enable cutting of beams, rods and piping etc. Compaction of concrete is discussed in chapter 6.3.1.4.

Each facility should also have a compactor for plastic- and cloth materials etc. which are routed for incineration. Insulation material should also be compacted before further storage and disposal.

6.2.4. WS4 – RWM handled by External Service Providers

Certain treatments require comprehensive infrastructure and facilities. In these cases, the best solution may be to use existing external companies/facilities for as long as they are certified and experienced in handling radioactive waste.

Amount

The MOA report estimates 175 tons of combustible material. 28 tons of this is assumed to be unconditionally cleared and can be sent for incineration at any incineration facility. 125 tons are to be handled through conditional clearance. The 210 tons of cables mentioned in chapter 6.2.2 should be sent for recycling in a specialized cable recycling company e.g. Metallco Kabel AS.

The 130 tons of material sent to external service providers includes mainly ~90 tons of metal scrap, 7 tons of resins and 17 tons of different liquids.

Treatment

Different types of material require different treatment, see subchapter 6.2.4.1 to 6.2.4.3

Storage

Active filters and ashes from the incineration are sent back to NND for storage and disposal.

Regarding melting, the pure metal is afterwards recycled and handled as conventional metal whereas the residues and separated substances will be sent back to NND for interim storage. Active resins after different kinds of treatment should be stored with regards to its exact content, probably at the interim storage as LLW.

Disposal

The remaining radioactive waste will be disposed of with regards to its nuclide content and activity level, generally as LLW.

6.2.4.1. WS4a – Incineration

As part of the combustible waste can pass clearance before incineration, the incineration can be done in a conventional facility for recycling of energy. Combustibles from the controlled area, especially secondary waste, are sent for incineration at special incineration facilities certified for radioactive material. In accordance with the waste hierarchy (ch. 4.2), the materials content of energy is recycled.

After measurements of activity content and nuclide composition, this material can be sent for incineration. Firsthand choice facility is the Senja plant in Troms fylke [17] or similar facility where they are used to handle active material.

6.2.4.2. WS4b – Melting

Metal with a layer of oxides or other form of contamination that cannot be seen as ETD is sent for melting. In this way, the oxide layer adhered to the surface and containing contamination of different kinds can be separated from the pure metal. As the molten oxides generally have a lower density, they will float on top of the molten steel, and can thus be separated. This melting is handled by special metal treatment facilities certified for melting of radioactive material.

This type of melting should be handled, e.g., by Cyclife Sweden AB in Studsvik (Sweden), or a similar certified facility.

6.2.4.3. WS4c – Treatment of Spent nuclear fuel

There are currently around 17 tons of spent nuclear fuel in Norway. This consists of fuel assemblies and individual fuel rods. Some rods are whole while others have been sectioned for PIE. Some of the rods are damaged or failed. The inventory is characterized by a large variation in fuel and clad materials, dimensions, enrichment and burn-up.

The Norwegian Ministry of Trade, Industry and Fisheries (Nærings- og fiskeridepartementet, NFD) has commissioned several studies on the management of Norway's spent fuel. The first studies were conducted by committees established by the ministry, and in general made two principal recommendations: firstly, that metallic uranium fuel and fuels with aluminum cladding, termed "unstable", and accounting for 72 per cent of the inventory, should be stabilized before disposal; and secondly, that use of overseas services should be preferred over construction of new facilities in Norway. Such stabilization can be achieved through dry oxidation by Studsvik in Sweden or through reprocessing by Orano in La Hague, France. These investigations have undergone the concept phase and external quality assurance (KS1) in accordance with the government's project model (R-108/19) in the period 2020-2021.

DSA gave feedback in their review of KS1 that the content of the report was not aligned with their requirements for any future applications from the licensee for treatment of spent fuel. They highlighted in particular their view that a national solution and direct disposal had not adequately been investigated. DSA thus highlighted a misalignment between the requirements of the nuclear regulatory authority and the government's project model.

As a follow-up to DSA's feedback on KS1, NFD has given NND the assignment "Clarification phase for the project Handling of Norwegian spent reactor fuel". The assignment's main output is to be a recommendation to NFD on which treatment method or combination of methods best achieves the societal objectives and user goals (*samfunnsmål* and *effektmål*). In contrast with previous studies, the recommendation is be made using DSA's input and guidance on what information, studies etc. will be necessary and sufficient to satisfy requirements for future applications. The study is scheduled to be completed in mid-2025.

The inventory contains a limited amount of HEU-Th fuel, which is defined as weapons usable nuclear material and thus presents a security concern. Norway is committed to eliminating its holdings of HEU, and NFD, IFE and NND have entered into a partnership with the US Department of Energy / National Nuclear Security Administration (NNSA) to treat the material. The method is based on experience at Savannah River National Laboratory (SRNL) and involves melting the fuel together with natural or depleted uranium and stainless steel matrix material. The resulting metallic waste form is of low attractiveness for weapons use and is suitable for storage and disposal. Treatment would be done in a mobile facility, Mobile Melt Consolidate (MMC), which is being constructed at SRNL and will be transported to IFE, Kjeller. MMC may also be an appropriate method to treat other fuel types, including metallic uranium. This will be investigated further during the Clarification phase for the project Handling of Norwegian spent reactor fuel.

The spent fuel, including any products from oxidation, reprocessing or melt treatment, must be stored until it can be transferred to a disposal facility (ch. 6.2.8). Storage is planned in a new facility on the interim storage site. If the fuel is treated abroad, storage for a period may be possible at the treatment facility.

6.2.5. WS5 – Disposal of VLLW

Amount

This waste stream contains 2550 tons of material, equal to 6% of the total decommissioning waste amount. This route contains according to MOA (see ch. 5.4 in this report), exclusively 1300 tons soil and 1250 tons concrete. It will thus be gathered towards the end of the dismantling phase and during the demolition phase.

Treatment

Material bound for landfill does not undergo any specific treatment. Landfill itself can be seen as a long term decay storage, which is sometimes considered a kind of treatment.

Interim storage

The material should be stored at the Kjeller site until a new site for the interim storage is chosen and a landfill for disposal of VLLW is commenced. The VLLW will require storage until the landfill is established, a conservative assumption is 10 years after start of decommissioning. An assumption is made that 10 % of the waste will be handled during the dismantling phase, during years 1 to 10 of the decommissioning, which requires and accumulates around one half-height container every year.

Disposal

The landfill should be placed in the vicinity of the interim storage once the location is decided. The landfill will be placed on a local high-point to avoid contact of the material with ground water. The storage will be well drained through a number of different layers above ground and will have a waterproof mat on top covered by a layer of around 1 m of conventional soil. This way the leaching of radioactive particles to the ground water will be kept at a minimum.

Larger plants having roots with a risk of harming the waterproof cover will be removed.

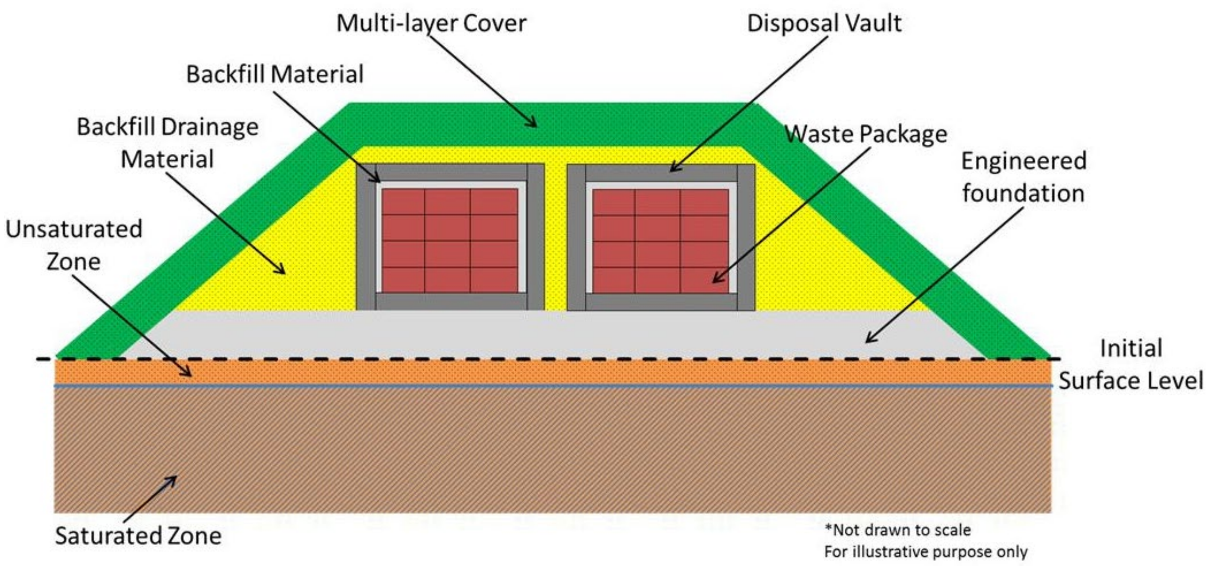

Figure 10: Principal sketch of the planned VLLW disposal at a new site

The landfill will be placed within the fenced area and thus be under surveillance for several decades, after which the specific activity will allow unconditional clearance. Until then personnel and other people are protected from exposure by the thick cover of soil, the limited presence of people within the fence, and the measures taken for avoiding ground water flow through the storage area.

6.2.6. WS6 – Disposal of LLW

Amount

This waste stream contains 1460 tons of material which equals 3,2% of the total waste amount. The main categories are 580 tons of concrete and 520 tons of components (ch. 5.4).

Treatment

After removing ETD-material and material fit for ESP's, the remaining LLW-material is not further decontaminated. Depending on material category, type and shape of material, authorized personnel will judge whether compaction is feasible and appropriate. Material is put in bags or boxes for measurement of specific activity. Piping and metal waste can be cut down and compacted to ensure optimum filling of the boxes. The cutting method should be chosen so as to not release air-borne particles or active gasses, preferably through using cold cutting methods.

Insulation and soft non-combustible material are compacted in a compressor and bound with straps.

Storage

After measurements the waste bags and boxes are put into containers which are transported to the intermediate storage facility. If required, additional shielding can be provided by steel or concrete tanks.

After measurement, concrete is packed in half-height containers as it is, i.e., either in large blocks or as scraps or pulverized material. Crushing of concrete to optimize filling of the containers is not used as the containers generally will in any case reach their maximum weight.

The LLW will require storage until a disposal facility is established. The waste amount, probably around 70 containers (partly full-height, partly half-height), is built up with equal amounts throughout the 15 years of decommissioning and will be stored at Kjeller until the interim storage facility at a new site is commissioned.

Disposal

After storage the material is finally conditioned and placed in the National disposal facility.

6.2.7. WS7 – Disposal of ILW

Amount

This waste stream contains 860 tons of material which equals 1,9% of the total decommissioning waste amount. The main categories are 370 tons concrete and 410 tons components.

Treatment

Due to its small volume and high dose rates, treatment of this waste is kept to a minimum. Any treatment is normally performed in a shielded compartment.

Storage

ILW material such as the reactor tank and primary circuit should be cut down and packed in well-shielded molds. Ion exchange resin (IER) will be stored in shielded molds. The waste is primarily produced during first years of the decommissioning. The molds should be stored at Kjeller until transported to an intermediate storage at new site before being finally conditioned and placed in the disposal facility.

Disposal

The material will be disposed in the National disposal facility.

6.2.8. WS8 – Disposal of SNF

Amount

As mentioned in chapter 5.1 there are currently around 17 tons of spent nuclear fuel in Norway. The amount to be disposed will depend on which, if any, treatment method is chosen. Direct disposal or oxidation will not significantly change the amount. Melt consolidation would increase the volume and mass, due to the extra stainless steel matrix material introduced, while reprocessing would significantly decrease the amount as ownership of separated uranium and plutonium would probably be transferred to Orano, and only six or seven canisters of vitrified fission product waste (approximately 1,5 m high and 45 cm diameter) would be returned to Norway for storage and disposal.

Treatment

As described in ch. 6.2.4.3, some or all of the spent fuel may be treated by one or more of the following methods:

- Repacking for direct disposal ("mechanical treatment")
- Oxidation (metallic uranium fuel)
- Reprocessing
- Melt consolidation

Storage

The spent fuel, including any products from oxidation, reprocessing or melt treatment, must be stored until it can be transferred to a disposal facility. Storage is planned in a new facility on the interim storage site. If the fuel is treated abroad, storage for a period may be possible at the treatment facility.

Disposal

The concept for disposal of SNF has not yet been decided. Two concepts are under investigation: (i) Deep Geological Repository (DGR) of the KBS-3 type and (ii) Deep Borehole Disposal (DBD). Other aspects of disposal that are being investigated include whether all radioactive waste, including spent fuel, should be disposed of in a single facility ("National disposal facility") or whether different waste types should be disposed of in separate facilities. These facilities may be located on the same or on different sites.

6.2.9. WS9 – Disposal of other types of long-lived waste

The MOA-report has not anticipated any material specifically in the category Long-lived waste. However, there are certain amounts of waste with a significant content of long lived nuclides stored at both sites as well as in KLDRA, partially mentioned as legacy waste in the MOA-report. [37] The solid long-lived waste kept at the Halden site has so far been put in fuel assemblies and stored in fuel storage positions.

Amount

Kjeller:

- 40 tons of liquid/sludge
- 24 tons of solid material such as components and material from the fuel fabrication.
- 1,6 tons of radium needles

Halden:

- 20 tons of fuel assemblies without fuel but filled with other contents such as minor components or parts of components from fuel tests etc.
- 20 tons of activated fuel pit lining

- 20 tons of components, where fuel transport utilities are half and lead shielding from a tomograph is the other half.

KLDRA:

- 90 tons of used fire alarms with contents of Am-241 (waste amount divided between Kjeller and KLDRA)
- The long-lived legacy waste kept at KLDRA is generally Pu-contaminated soil, an amount of 39,8 tons, which is kept in 166 barrels.

Treatment

The metallic material kept at the Halden and Kjeller sites is very heterogenous both with regards to specific activity and to the composition of isotopes. The material is generally assumed to be both activated and contaminated, and thus cannot be cleared. In many cases information about the waste is insufficient or unavailable.

A reasonable way to manage this material is to treat it generically according to a worst case scenario, i.e., according to conservative dose rates and risk of spreading. This means treatment is minimized and focus will be to store the material in a safe way before disposal.

It may be possible to treat the soil currently stored in KLDRA, as mentioned above in chapter 5.3. According to the MOA-report, the material seems to have activity levels just around the clearance level. MOA's recommendation is to send half of it for conditional clearance and the other half for processing as VLLW. It should though be noted that landfill is not a solution for long-lived waste. Further information about the soil is needed, including activity levels and scaling factors, before a decision on treatment can be made.

Storage

Metallic and liquid waste should be stored in boxes or molds with regards to its activity level. It should be placed in Kjeller until transfer to the interim storage.

The soil and other long-lived waste today placed in KLDRA should be further examined. A decision has to be taken together with DSA if it can remain there until a decision for disposal is made.

Disposal

Long-lived waste should generally be disposed in a Deep Geological Repository (DGR) or/and a Deep Borehole (DBD)

6.3 Assignment of waste categories to the different waste streams

6.3.1. Concrete

The decommissioning team, together with the contractor and waste department, must evaluate before demolition in which cases to use sawing techniques and in which to use other techniques such as, e.g., a Brokk tool.

6.3.1.1. Contaminated concrete

The contaminated concrete extracted during the dismantling phase generally comes from machining of floors and surfaces and is thereby more or less pulverized. As floors are generally the most contaminated areas, the contaminated concrete in many cases includes a layer of epoxy floor paint and is thereby also considered hazardous.

This type of concrete should generally be stored and deposited as VLLW or LLW.

6.3.1.2. Neutron activated concrete

The activated concrete from reactor tank shielding and fuel pool walls must be carefully labeled with both position and orientation within the shielding. Generally, the concrete is activated from RT and a few decimeters into the material, and the remaining material outside of that can go through clearance.

After the material has been characterized (activation level and depth), it should be assessed which parts of the concrete can be cleared and which to treat as VLLW or LLW.

6.3.1.3. Non-contaminated concrete

After dismantling is done and contaminated floor- and wall surface layers are removed, buildings are cleared and then demolished. The main part of the concrete waste arises during the demolition phase, i.e., after the buildings has gone through clearance. Concrete from the demolition phase generally comes in larger blocks, depending on the chosen method of demolition.

As this is conventional waste it should be decommissioned with regards to its future use. It is generally beneficial to use this material for backfilling the void volumes after the buildings have been demolished.

6.3.1.4. Crushing of concrete

Crushing of concrete could optimize filling of the containers. This will reduce the number of transports and optimize the volume in the disposal for activated/contaminated concrete. However, a normal half-height container will weigh approximately 20 tons even without crushing of the concrete, and thereby limit the benefit of further compaction.

Crushing the concrete will also make substances more soluble and thereby ease transports of nuclides/particles with the ground water streams. For this reason, it is better to cut out and maintain the most induced concrete in the form of blocks.

Crushing of concrete is also an extensive work requiring heavy machines and causing air-borne, possibly radioactive, particles. These risks to personnel safety must be evaluated before a decision is made.

If crushing of concrete is chosen as a general technique, the crushing must be evaluated with regards to specific input for each concrete structure, due both to personnel safety aspects and to possible effluents from the crushed concrete.

6.3.2. Insulation

The estimations point out an amount of 12,5 tons of insulation from decommissioning. 2,5 tons of this can be unconditionally cleared while 10 tons is expected to reach an activity level requiring conditional clearance.

The whole amount will be routed for compaction, after which the compacted material will be sent to interim storage and disposal since this type of material cannot be incinerated nor recycled in a feasible manner.

6.3.3. Active Liquids

Excluding the 17 tons handled as ESP-material, this waste stream contains 70 tons of active material which equals 1,6 ‰ of the total waste amount from decommissioning. Existing liquid waste should as far as possible be handled as part of the POCO. Liquid waste will however also arise during the decommissioning.

The total amount of heavy water is assumed to be around 25 tons. It is expected that it will be possible to recycle it for use in other research reactors although its tritium content may be challenging. If recycling of the heavy water is not possible it should primarily be solidified in the concrete used for final conditioning of other waste and only as a last option disposed in drums.

The primary circuit should be emptied as part of the POCO, and the heavy water are aimed to be removed from the site before commencement of decommissioning.

6.3.4. Ion Exchange Resin (IER)

Around two tons of resin are considered to be clean while around 7 tons are to be stored in shielded drums or molds until disposal commences. The clean resins can be sold and reused, or alternatively treated according to conventional regulations for chemical substances.

6.3.5. Processing of DSRS and medical RW

Disused sealed radioactive sources and other wastes, e.g., medical RW, are continuously received from society. These radiation sources should be treated with regards to their level of activity and the nuclides involved. A large part of this waste is VSLW and should thus be stored and allowed to decay before being cleared. These sources are generally alpha- or beta emitters, which means the radiation is easily shielded during the required storage time.

6.3.6. Hazardous waste

The MOA-report has not anticipated any material belonging to the category Hazardous waste. It is thus difficult to predict amounts and types before a physical categorization of all waste is done. The work on categorizing and handling hazardous waste will take the form of a sanitation plan, and operations handled by special companies with the necessary expertise in this field.

Most probably however significant amounts of asbestos will be found. Contaminated or not, it should be taken care of and routed for storage and subsequent disposal.

Before demolition of buildings, concrete samples should be taken and analyzed for Chromium (VI) content. If required, the material should be handled according to general procedures for chromium (VI) in combination with possible activation or contamination.

6.4 Conclusion of material and treatment

Table 3 displays a simplified table of materials, amounts and suggested treatment methods for the decommissioning waste. The amounts for WS1 to WS7 have been taken from the MOA-report, see table 2 in this report.[6] Amounts for WS8 and WS9 have been added.

After being dismantled, <u>all</u> material must be cut into pieces which fit into the containers used for radiological measurements. The material will then be characterized (dose rate, specific activity and scaling factor) to either allow clearance or to specify the appropriate waste stream.

Table 3: Amounts of waste in different waste routes

	Material	tons	treatment	tons	storage / disposal	tons
WS 1	Exempt waste	37 520	-	-	-	-
WS 2	Conditionally cleared mtrl.	2140	-	-	short term conv. storage	2140
WS 3	Internal treatment	265[7]	Decont, Segr. etc	265[6]	only residues	27[8]
WS 4	External treatment	130	Melting etc[9]	130	only residues	13[10]
WS 5	VLLW	2550	-	-	Landfill	2550
WS 6	LLW	1460	-	-	National disposal	1460
WS 7	ILW	860	-	-	National disposal	860
WS 8	SNF	17	oxidation/reproc.	10	National disposal	17
WS 9	Long-lived	164	-	-	National disposal	164
Unknown	Concrete and metal	210	unknown	210[11]	unknown	210[10]
Summa		45 316		615		7 441

The table shows that only minor amounts of waste require treatment and storage as well as deep geological deposition. Less than 1000 tons require treatment, and the Interim storage facility will receive less than 3000 tons each for the landfill and the storage building. Thus, also less than 3000 tons will require space at the National disposal facility.

[6] The operational waste and external waste are thus not covered, but the amount is, as shown in figure 4, judged to be negligible in comparison to the decommissioning waste amounts.

[7] Treatment of liquids (70 tons) and heavy water (25 tons) has been added to the original ETD-value (170 tons) from table 2.

[8] Decontamination will cause a minor amount of active secondary waste such as IER, filters or blasting material that has to be stored and disposed of. In this case a proportion of 10% of the original mass is presumed.

[9] Other treatment methods will also be used, but melting is valid for main part of this material.

[10] Melting of material will cause an amount of active cinders/residues that have to be stored and disposed of. Incineration of material will cause an amount of active ashes and filters that will be returned and must be stored and disposed of. In this case a proportion of 10% of the original mass is presumed.

[11] Conservatively the whole amount has been added both for treatment and storage.

Assuming that a total of 500 tons of waste require treatment over a period of 15 years, as discussed in chapter 3.2, there will be an average throughput of 0,64 tons of waste per week, divided between both the different sites and different treatment stations. However, the treatment infrastructure should be dimensioned to handle uneven throughputs and unanticipated problems leading to clogging of material etc. Similarly, all storage facilities should be dimensioned to handle worst case scenarios, such as failure to obtain needed equipment, contracts, licenses and permissions in time.

The information presented in this chapter shows that the equipment for internal treatment is not very advanced. The costs for this equipment are minor compared with other costs, such as licensing and resource requirements. Therefore, all sites (Halden, Kjeller and the new site for centralized storage facilities) should be equipped with the necessary equipment to avoid waste treatment bottlenecks.

7. Facilities and infrastructure for management of radioactive waste

The availability of facilities and infrastructure will change during the progress of the project. Initially, existing facilities will be used. Within a few years there will be further facilities available within existing nuclear sites. After yet a few years a new nuclear site will be commenced focused on pre-treatment and interim storage of RW. Finally, after a few decades we should be able to open the disposal for RW and thus start transferring waste there from the interim storage.

Existing facilities and sites will be closed after they are emptied of their nuclear contents and released from regulatory requirements. Later, the storage facilities at the new site will be closed as their contents are transferred to disposal facilities. In the long term only a facility for treatment of incoming societal RW, the landfill and the disposal facilities will remain.

Below is an illustration of the different phases, given with a vague estimate of time periods.

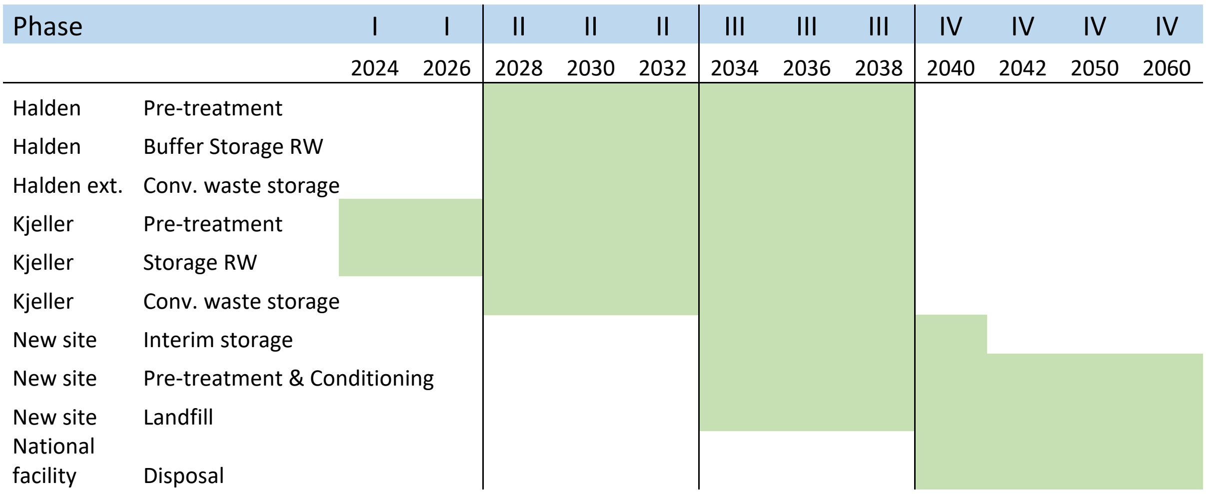

Figure 11: Illustration of waste facility phases (with a very vague estimation of time for implementation and phase-out)

7.1 Phase #1: Present Operation (Transition)

Since 2019 the Norwegian nuclear research facilities have been shut down and are awaiting decommissioning. The regulatory position is however that the facilities are still defined as being under operation. As of today the waste treatment thereby continues according to the existing WMP [1] in line with requirement 8.42 and 8.43 in [32]. One important difference compared to current situation however is that clearance procedures should be updated to be in line with the valid regulations [11], which would allow far more material to be cleared than is possible under current procedures. This is further discussed in chapter 4.7.

The focus during these first years should be to employ needed personnel, get an overview of the dismantling and waste management market, build up relations to partners and contractors as well as preparing contracts to relevant companies. Other important areas are to get an overview of the facilities, e.g characterize the future waste, and to prepare the sites through e.g. system decontamination and POCO. It is also to establish procedures and prepare both physical and administrational infrastructure for the coming decommissioning. The production of waste will thus not be a primary concern during phase 1.

Table 4: Waste treatment performed at the Radwaste facility today [40].

Type of treatment or conditioning	Purpose	Waste types	Description
Grinding and pressing	Volume reduction and packaging	Solid non-metal LLW suitable for grinding.	Solid LLW from laboratories and facilities is ground and pressed in barrels. Concrete-shielded drums can be used as needed.
Casting of waste into waste package containers	Packaging	Metals and other non-compressible materials.	Casted into steel barrels, concrete molds, or steel boxes.
Solidification and casting	Solidification and packaging	Ion-exchange resin and other liquid waste	Liquid waste and ion-exchange resin (semi-liquid masses) are solidified with the addition of cement or additives. Solidified ion-exchange resin is packed in special steel containers in concrete and/or lead-shielded barrels.
Dismantling of components	Volume reduction by separating the radioactive and non-radioactive materials of a component.	Components	The radiation source is removed and sorted.
System for collection and handling of internally generated liquid waste	Collection, storage, and effluent of liquid waste	Low-level liquid waste generated at the site.	Liquid waste is collected at Radwaste through pipes from various facilities on the site. The liquid wastewater is stored in tanks for decay and released though the NALFA pipe to Nitelva under monitoring of the activity. An evaporation system can be used if the wastewater contains radioactivity levels or specific nuclides which limits emission through the NALFA pipe. If necessary, the water can be purified with an ion-exchange column.
Evaporation system	Solidification and volume reduction	Liquid waste with radioactivity levels or specific nuclides which limits emission through the NALFA pipe.	An evaporation system is used for liquid waste. The evaporator concentrate is collected and transferred to solid form in steel barrels with the addition of cement.

Existing installations include storage facilities for fresh and spent fuel, treatment facilities for radioactive waste and a laboratory for handling spent fuel and radioactive substances. The relevant facilities related to waste management are summarized in Table 5 and 6:

Table 5: List of facilities at IFE Kjeller for management of radioactive waste.

Facility name	Purpose		Waste type	Built
Radwaste	Treatment and conditioning of radioactive waste		VLLW-ILW	1958
Storage building 1	Waste storage		VLLW-ILW	1966
Storage building 2	Waste storage		VLLW-ILW	1978
Metlab II (Brønnhus)	Inspection, testing and storage of used fuel		Used fuel	1965
JEEP I stavbrønn	Dry storage of used fuel		Used fuel	1965

Table 6: List of facilities at IFE Halden for management of radioactive waste.

Facility name	Purpose	Waste type	Built
Fuel Bunker Building	Storage of used fuel	ILW- SNF	1958
Met lab.	Inspection of used fuel, storage of waste	VLLW-ILW	1996
Storage tunnel	Waste storage	VLLW-ILW	1976
Olavs hall	Waste treatment room, can be used for treatment or storage	VLLW	1972
Reactor hall	Storage of used fuel	VLLW-SNF	1955-1958
Delay room	Treatment and conditioning of liquid waste	VLLW-LLW	1958
Kapperom SB19B	Treatment and conditioning of RW	VLLW-LLW	2005

7.2 Phase #2: Start of decommissioning

The hallmark of waste management phase 2 is enhanced treatment and storage capacity at existing sites.

As the decommissioning phase commences, the waste flow from IFE's facilities will increase significantly. This requires first of all increased storage capacity, but also, with regards to the planned pace of decommissioning, increased capability in the infrastructure for treatment of waste. This will be handled through the addition of spaces for treatment and storage at existing sites.

As the decommissioning phase commences the first measures should be to clear space in both facilities to enable this extension of clearance, treatment and storage capabilities.

7.2.1. Halden

To date only limited waste treatment has been performed in Halden. The treatment abilities can be greatly enhanced by arranging new process for clearance of material and by building a new building for treatment of ETD-material and a buffer storage. It should be evaluated whether the capacity of the water treatment facility should be enhanced in order to handle the additional water from, e.g., the water blasting and demolition works. A cutting station and clearance station can be placed in Olavshallen to enable the dismantling team to cut, pack and measure the waste on its way out of the facility. To enable this the steam generator, hotwell, tertiary circuit pumps and SCB's should be removed to widen the tunnel and create a working area in the wider part of the tunnel by the tertiary pumps.

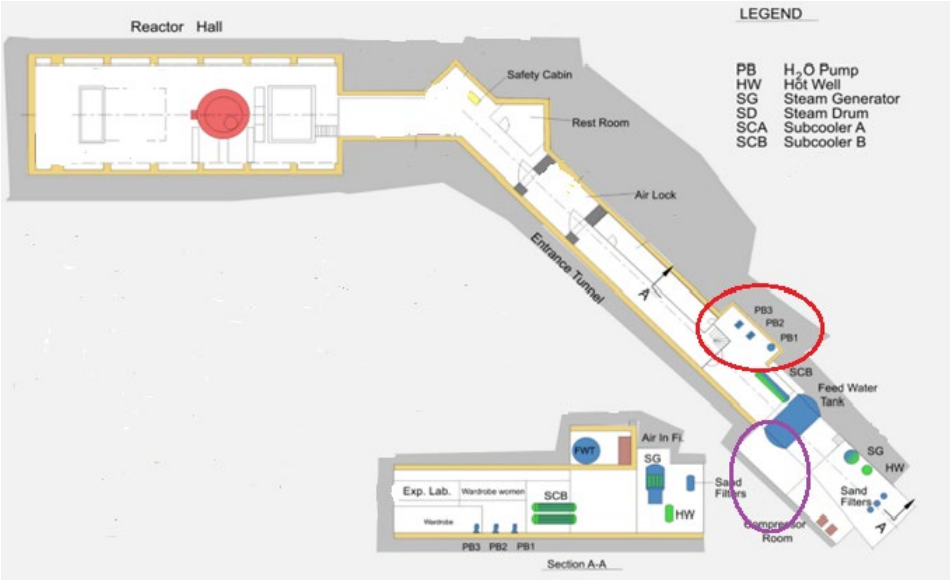

Figure 12: The Halden entrance tunnel to RH with marks for treatment and measurement stations

Red ring: Widening of exit tunnel that can, after removal of three pumps, be used for segmentation and further dismantling of material before measurements.

Lilac ring: Spot where todays measurement station should be removed and replaced by new measurement and clearance equipment.

The new building can be placed west of Olavshallen. A project for launching this work should be started as soon as possible. The building should contain a buffer storage/hand-over point where packed and measured waste is received from the dismantling teams. At receival of the waste, the waste team verifies the package labeling and decides whether the material should go through treatment or be directly directed to next buffer storage to await transport to a conventional storage or to Kjeller.

ETD-waste is treated in different decontamination stations within this new building. One room is dedicated to ordinary cleaning/wiping. Another room is arranged with a water spool box for water blasting. A third room is arranged for other types of blasting. A fourth room is arranged for mechanical treatment (hot works). Glove boxes for handling of ILW and legacy waste are located in today's facility in FBB.

Two alternatives for this concept solution are given in the following pictures:

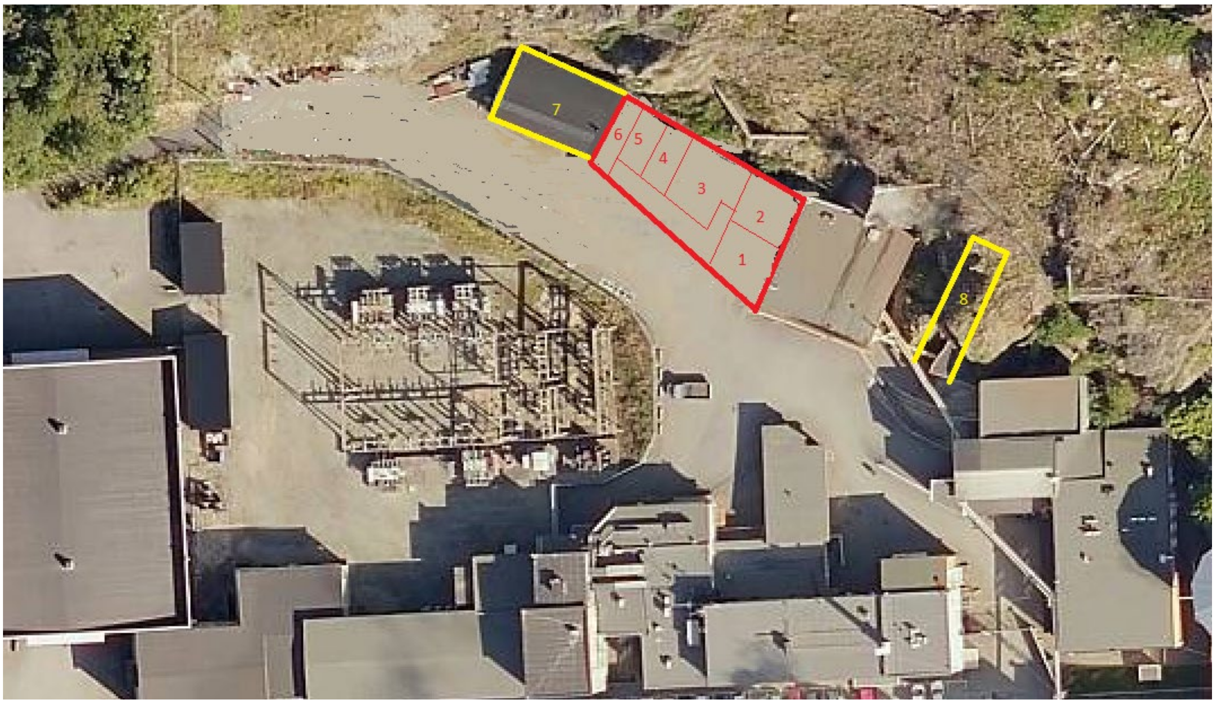

Figure 13: Additional building in Halden, between Olavshallen and the Madison building

Yellow markings showing existing Madison building and waste tunnel. Red markings showing the new Treatment & buffer storage building, with rooms/divisions according to the following:

1.) Waste hand-over point and Buffer storage before decision of needed treatment (WS)
2.) Room for spool-box and liquid treatment
3.) Room for segregation, wiping and segmentation, including workshop
4.) Blaster hall
5.) Buffer storage for LLW before transport
6.) Room for compactor
7.) Buffer storage for cleared waste before transport
8.) Buffer storage for ILW and hazardous waste before transport

An alternative with a larger new building including a corridor from Olavshallen is shown below.

Figure 14: Alternative larger building in Halden after removal of Madison building

1.) Waste hand-over point and Buffer storage before decision of needed treatment (WS)
2.) Room for liquid treatment
3.) Room for spool-box
4.) Room for segregation, wiping and cold workshop
5.) Hot workshop / segmentation
6.) Blaster hall
7.) Room for compactor
8.) Buffer storage for LLW before transport
9.) Buffer storage for ILW and hazardous waste before transport
10.) Buffer storage for cleared waste before transport

As Halden has limited space there has to be recurrent transports to a larger storage facility, and as the only allowed space for this is Kjeller (until a new site is commissioned), the radioactive part of the waste has to be transported there. The cleared waste on the other hand is transported to a conventional industry site before deciding where to route the different types of waste.

7.2.2. Kjeller

Processing and pretreatment of radioactive waste will be continued in the Radwaste facility at Kjeller which has been used for this purpose since 1958. Radwaste is a facility for management of VLLW-ILW and is used for receiving, sorting, handling and treatment. The facility will continuously have to receive all VLLW-ILW generated from external sources in Norway as well as from IFE´s own operations at Kjeller and Halden.

As Kjeller already has significant capabilities for treatment, the main focus should be on arranging necessary facilities for clearance of waste and creating enough storage space for radioactive waste until an interim storage is in place.

The possibilities to increase storage capacity in existing buildings should be investigated. Possibly, the JEEP 1 reactor hall can be used after dismantling of the bulk of systems and components there. Probably there will also be a need for further space requiring new temporary buildings to be built. It should be noted that only RW has to be stored in this facility. Cleared waste from, e.g., the dismantling of N0RA can be transferred to a conventional storage facility outside the Kjeller nuclear site. Possibly also part of the waste from existing storages can be cleared and removed, thus creating space in existing storage facilities.

7.3 Phase #3: Later decommissioning phase

The hallmark of phase 3 is the commencement of a new treatment and storage facility at a new site.

NND plans to commission a new waste handling and storage facility on a new nuclear site by the mid 2030's. A concept study is under development, as support for the on-going process, to locate and purchase a feasible location, and design and construct the appropriate facilities. The process includes obtaining all necessary regulatory approvals.

7.3.1. Location of additional facilities at a new site vs. at Kjeller

Instead of deploying facilities at a new site, especially NFD has advocated to use existing space at the Kjeller site. This is evaluated in [41]. NND has concluded it not to be a competitive solution due to for example the following reasons:

- The area is managed by IFE. IFE have plans to develop this area into a broader research facility of national interest within different fields of energy technology.
- IFE is engaged in fulfilling regulatory requirements, e.g. updating of SAR. This work will last for at least a couple of years before the area can be transferred to NND. Thus, even if NND would change the plans for the area it would delay the matter several years in comparison to start elaborating plans for another area.
- Lillestrøm kommune is reluctant to this matter, they want to clear the area from nuclear related business in order to promote the emergence of a research park.
- The area has limited space.
- Regulations limit the use of remaining area.
- The area is populated and located relatively close to the capital area.
- Uncertainties regarding the allowed use of the area are higher.

Actually the evaluation concludes that the only benefit of using the existing site is the initial investment cost. [41]

7.3.2. The new site

The new site should preferably be located between Kjeller and Halden to reduce the transportation distance. So far six locations have been evaluated, all within 50 km of Halden. Co-operation agreements have been signed with Halden and Aremark municipalities and initial geological screening is being made by NGU. The site should have enough space for a possible landfill storage for VLLW, a facility for treatment and storage of decommissioning waste, a storage facility for SNF and storage capacity for national RW arisings from the next five decades. Needed treatment capabilities and storage capacity are given in chapter 6.

When entering this phase, the conventional buffer storage can be moved to the new site and the site that has been used so far can be released for other industrial purposes. Treatment of RW on the Halden and Kjeller sites will initially be maintained and used in parallel with the new facility.

After the radioactive waste facility “Radavfall” in Kjeller has been decommissioned this new facility should be the sole national facility for general RWM. However, for certain services, such as e.g. incineration or metal melting, ESP’s should also in future be contracted.

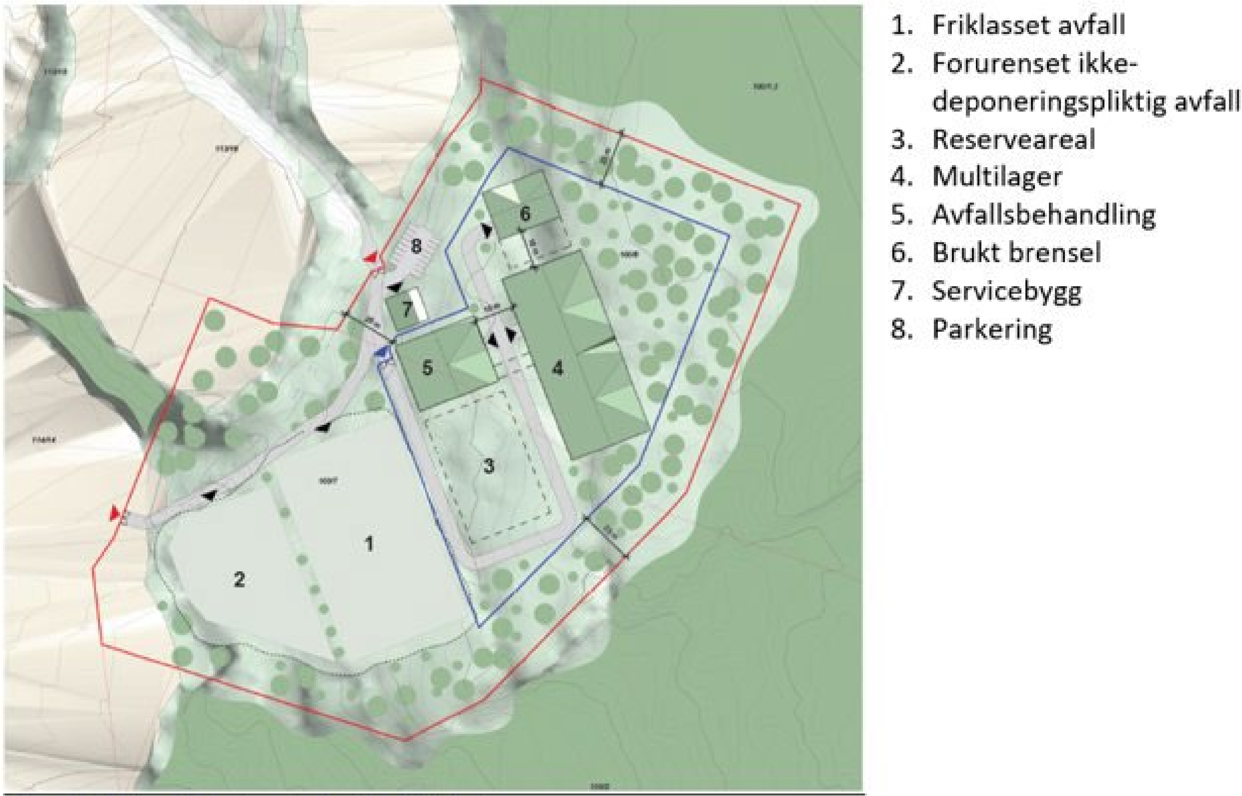

Figure 15: Example from the planning of a facility on a possible new nuclear site (Rokke) [41]

7.3.3. The new Radioactive Waste treatment Facility

Initially, the existing treatment facilities in Halden and Kjeller should be used in parallel as it is advantageous to perform treatment as close to the waste source as possible. However external waste can be directed to the new facility from the start to relieve the old facilities from part of their load.

This third set of equipment will cause extra expense, but it will not constitute a major cost as it reduce some significant bottle necks and enable a higher waste throughput.

Along with the progress of the decommissioning of the old IFE facilities, both treatment and storage will be successively transferred to the new site. After Metlab 2, Radavfall and Storage facility 2 are decommissioned, all processing and treatment of Norway's radioactive waste will be continued on this new site. The facility for management of VLLW-ILW will be used for receiving, sorting, handling and treatment. The facility will receive VLLW-ILW generated from external sources in Norway as well as from the decommissioning of IFE´s facilities at Kjeller and Halden.

7.3.4. Landfill

Short lived VLLW should primarily be routed to a landfill. Primarily a landfill should be established at the planned Interim storage site. A landfill should be designed to be built above the surrounding ground in order to prevent ground water from reaching the waste and thereby prolong the time before degradation of the storage containers can lead to release of radioactivity.

7.3.5. Radioactive Waste Storage facility (LLW+ILW)

The interim storage should have a 3000 m^2 hall for containers, boxes and drums. A part of it should be reserved for ILW and thus be equipped with additionally shielded walls.

7.3.6. Spent Nuclear Fuel Storage Facility

The dimensions of the spent fuel storage facility will be dependent on the concept chosen. IFE is currently conducting a public procurement process for the facility. The facility should be designed with regards to applicable security requirements for the safeguard of spent fuel. In connection to the fuel storage there should also be a 400 m^2 hall for fuel treatment/inspection.

7.4 Phase #4: Permanent (National) Disposal

The hallmark of phase 4 is availability to the National disposal facility.

The treatment facility discussed under chapter 7.3 remains in operation for treatment and conditioning of waste as well as landfill disposal of VLLW, while LLW, ILW and SNF after treatment is transferred to this disposal.

Preparatory work i.e. knowledge acquisition regarding a number of locations is just starting up, to form a basis for this siting process of the "national disposal".

7.4.1. Disposal program strategy

The planning and disposal of radioactive waste will follow the stepwise approach described in IAEA SSR-5 [42] with evaluation and decision points for each step. This approach will ensure confidence in safety and a mutual understanding among stakeholders on, for each step, key issues to either close or to further assess. The licensing process including siting, disposal concept/design, construction, operation, and closure developed by NND will be the main driver within the disposal program. Supporting functions within NND will deliver input for each step and ensure that the licensing process is followed over time. These functions or processes are "Site characterization", "Safety assessment", "Environmental impact assessment" and "Design". Requirement management and knowledge management systems are to be implemented at NND to keep track of needs for each step as well as level of fulfilment.

7.4.2. Siting

NND will follow international standards, for example IAEA SSG-35, and the siting process is divided into four stages: concept, site survey, site investigation and finally the detailed investigation stage. The output for each stage will enhance the site understanding according to, and with focus on, requirements set in regulations and disposal concept demands. In parallel, the environmental impact assessment process is executed to ensure societal and stakeholder engagement and handling of expressed expectations. The siting process is planned to be running together with the licencing process and is driven by regulatory decision points set by the regulator.

7.4.3. Disposal concept

No disposal concept is yet decided upon and NND will, until concepts are developed, use analogue disposal concepts to show how the disposal program is linked to other parts of the waste management program (waste handling, interim storage, transport, and decommissioning activities). Analogues used here are taken from the Swedish disposal system (KBS-3 SFR and SFL) to cover all waste streams that need permanent disposal, see [43] and fig 14.

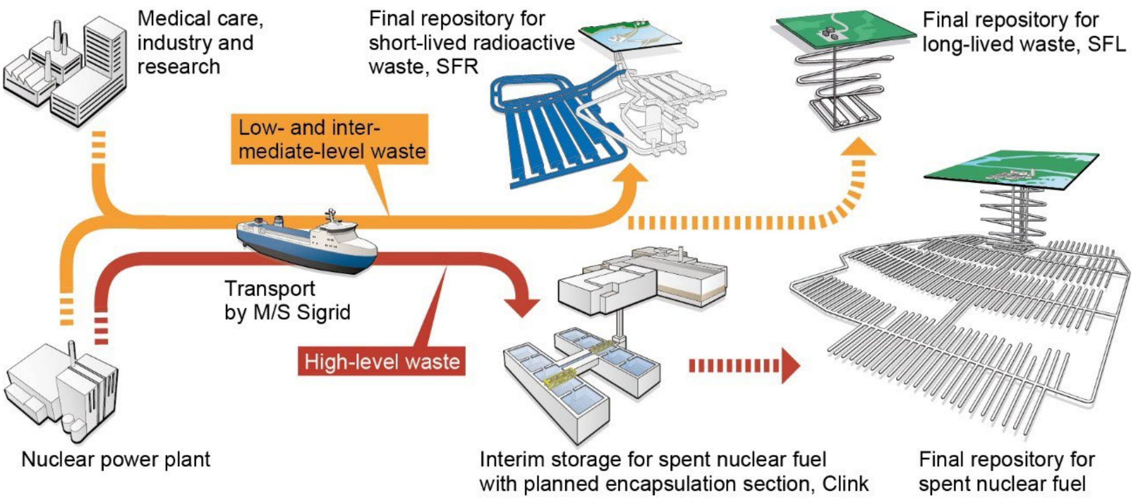

Figure 16: The Swedish system of disposal facility concepts (SFR, SFL and spent nuclear fuel).

7.4.4. Disposal system waste acceptance criteria (WAC)

As discussed above, there is a need to develop preliminary waste acceptance criteria, based on international practice, such that meaningful decisions can be made on waste treatment. These characteristics are here referred to as disposal system waste acceptance criteria. The WAC are defined to function within the disposal concept to ensure system behaviour in accordance with concept demands.

WAC typically encompass:

- Design, geometry and dimensions
- Weight
- Marking

- Radionuclide inventory
- Surface dose rate and dose rate at a certain distance
- Surface contamination
- Internal radiation
- Homogeneity
- Composition and structure
- Corrosion resistance
- Gas formation
- Combustibility and fire-resistance
- Chemical reactivity
- Leaching
- Mechanical strength against external stresses
- Mechanical stability

7.4.5. Examples on WAC criteria for Low and intermediate level waste (LILW)

These requirements are founded on the Swedish requirements gathered in reference [44] regarding the Swedish disposal SFR and its different cavern repositories in Forsmark, Sweden. They can be seen as a model for the Norwegian disposal, however they have to be checked to be in accordance with Norwegian regulations, and after choosing a site they have to be further customized to site specific conditions.

- **Surface dose rate.** The maximum surface dose rates allowed according to the Waste acceptance criteria for waste packages in the different waste vaults in Forsmark are given in the following table. It should be noted that the dose rate level used for BLA & BRT is the same as for LLW in general. It can also be noted that transport dose rate limits generally are lower than disposal limits.

Table 3-2. Maximum surface dose rates for waste packages in the different waste vaults [mSv/h] (implemented for SFR 1 and preliminary for SFR 3 (SKBdoc 1368638)).

Waste vault	Surface dose rate limit (mSv/h)
1BMA	100 (< 30 for 80%, > 30 for 20%)
2BMA	100
1BTF	10 (however the current transport system limits the dose rate to 8 for concrete tanks and 2 for drums)
2BTF	10 (however the current transport system limits the dose rate to 8 for concrete tanks)
Silo	500
1BLA	2 (the current transport system also limits the dose rate to 0.1 at a distance of 2 m)
2–5BLA	2 (the current transport system also limits the dose rate to 0.1 at a distance of 2 m)
BRT	2

Figure 17: Maximal surface dose rates allowed in different parts of the Swedish disposal.

- **Surface contamination.** Surface contamination should not exceed 40 kBq/m^2 for beta- and gamma-emitters and 4 kBq/m^2 for alpha-emitters. These are the same as the limits applied in the Swedish regulations for clearance of materials (SSMFS 2011:2). There are additional requirements for the waste packages and transport containers relating to transport.

- **Radiation effects.** Integrated dose received by cement or bituminised ion-exchange resins should not exceed 106 Gy. Experiments have shown that integrated doses above this level may give rise to swelling as radiolytic cleavage of functional groups from the resins leads to the formation of gaseous products.

- **Packaging**. The contents of the waste package should be distributed in a way that does not compromise the radiological safety. Some waste types have the additional requirement that they must be securely loaded before transport, so that the increase in highest surface dose rate is at the most 20% if the package is dropped. There are no restrictions regarding the homogeneity of waste allocated to the LLW-disposal, except for transport related requirements for some containers.

- **Chemical and physical requirements.** Chemical and physical requirements concern composition, structure, homogeneity, hydraulic properties, temperature, liquids, gas formation, fire resistance, chemical reactivity (complexing agents), leaching and environmentally hazardous substances.

- **Composition and structure.** Acceptance criterion regarding the chemical composition and structure of the waste form and waste packaging is that they shall be in accordance with the stated specifications given in the Waste type descriptions. There are guidelines for the quantities of materials allowed in the different waste vaults that should be upheld.

- **Homogeneity**. Waste forms that are stabilised with cement or bitumen shall be sufficiently homogeneous to ensure that the physical and chemical properties accounted for in the radiation safety and long-term safety assessments are not compromised.

- **Hydraulic properties.** Waste deposited in the ILW-disposals shall be solidified in cement or bitumen or embedded with concrete within the packaging. Waste deposited in the IER-disposal shall either be embedded with concrete inside the packaging, or the packaging should be a concrete tank. Containers allocated to LLW-disposal should withstand washing and rainfall/snowfall.

- **Temperature**. The waste packages should withstand temperatures between 0 and 30°C during storage, and down to –20°C for short time periods, for example during transport.

- **Liquids** The content of the waste package is not allowed to be liquid. Specifically, the waste shall not contain free or contained liquid.

- **Gas formation.** The rate and extent of gas formation in the waste packages and their contents shall not be sufficient to compromise the safety of the repository during operation or the barriers in the long-term. There are guidelines for the gas-production rates and quantities of specified materials allowed in different waste vaults that should be upheld if possible, of primary interest is the quantities of aluminium and zinc. The preliminary Waste acceptance criteria contain limits for gas-production rates and quantities of aluminium and zinc allowed in different waste vaults.

- **Fire resistance**. The waste package must not be subject to self-ignition, and it should withstand a short fire without unacceptable dispersion of radionuclides. Explosive substances are not allowed. The design of the packaging shall obstruct the spread of fire. The resistance to fire is explored in studies that are referred to in the Waste type descriptions. The containers allocated to the LLW-disposal shall have a total leakage area less than 2 dm^2. This leakage area includes leaks from door joints. No holes from corrosion or physical damage are allowed at disposal. This criterion is set to minimise the risk of an open fire in case of self-ignition inside the container.

- **Chemical reactivity (complexing agents).** The type and quantity of chemical substances that can form mobile complexes with radionuclides should be known and as far as possible avoided. Substances that are not suitable for deposition in a disposal are:

- N-carboxylated diamines, e.g. EDTA.

- N-carboxylated triamines, e.g. DTPA.

- N-carboxylated amino acids, e.g. NTA.

- Tricarboxylic acids, e.g. citric acid.

- α-hydroxi-carboxylic acids, e.g. glycone acid.

The concentration of dicaboxylic acid, e.g. oxalic acid, may not exceed $1 \cdot 10^{-2}$ mole in each waste package. Carbonate may not exceed $1 \cdot 10^{-2}$ mole in each waste package. There are limits for acceptable quantities of cellulose in the waste packages in the different waste vaults and also for the quantity of cellulose allowed in each waste vault. Introduction of a new substance during waste handling that may give rise to radionuclide complexation have to be assessed from case to case.

- **Leaching**. Waste allocated to the ILW-disposal shall be either solidified with cement or bitumen or embedded with concrete. There are also acceptance criteria related to the leakage of radioactive substances in the case of an accident during transport.

- **Environmentally hazardous substances.** The amount of environmentally hazardous substances shall be kept as low as possible.

- **Mechanical requirements.** Mechanical requirements concern the robustness against external influences and internal stability.

- **Robustness against external influences.** Waste packages allocated to ILW-disposal shall withstand stacking of 6 moulds or 8 drums grouted with concrete. Waste packages allocated to the IER-disposal shall withstand stacking of two concrete tanks with an overload of 30 kN, or 10 laid down drums. Waste packages allocated to the LLW container disposal shall withstand stacking of 3 full-height or 6 half-height containers. There are additional requirements for the waste packages and transport containers relating to handling and transport. These requirements are different between different waste types depending on differences in their way from the producers to disposal. The requirements are given in the Waste type description together with references to supporting studies. For the internal stability also swelling is assessed per waste type and waste vault.

- **Corrosion resistance.** Waste packaging shall have a corrosion resistance so that the packaging is intact at the time for concrete grouting or closure of disposal.

7.4.6. Example of container fulfilling WAC for long lived waste, e.g., reactor internals

Steel tanks are used for storage of internal parts and other long-lived waste from nuclear power plants (Fig. 15). It is planned to use these tanks also for disposal [45].

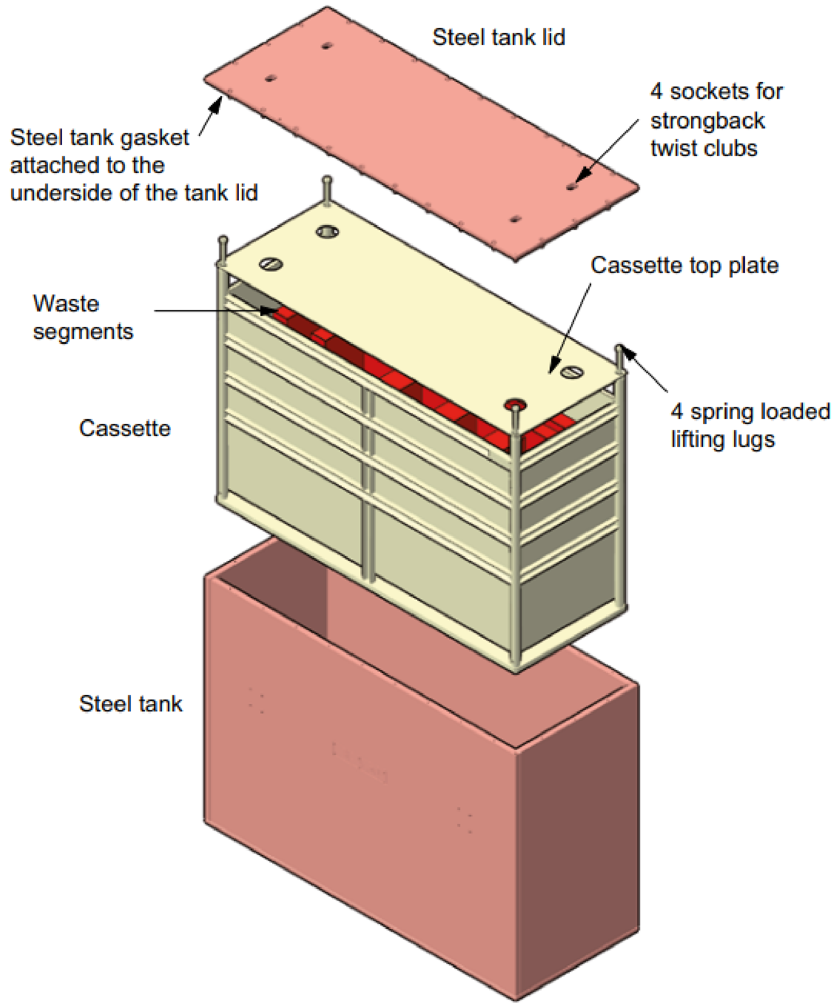

Figure 18: Conceptual illustration of steel tank for neutron activated components. [45].

7.4.7. WAC for spent fuel (KBS-3)

General waste acceptance criteria are available for KBS-3 [43] and NND will follow ongoing work at SKB and Posiva to further specify KBS-3 method standards as part of updated versions of this report.

8. Transportation of radioactive waste

Transportation can be divided into three different categories: International transports, transportation carried out nationally between different sites, and internal transports carried out inside the boundaries of a site.

Applicable laws and regulations for transportation of radioactive waste and materials are described in chapter 2. Furthermore, NND will adapt IFE routines for performing transports of radioactive material, described in IFE´s requirement document for transport of nuclear materials [19].

In line with general safety routines the transports should be well planned, and afterwards feedback should be given and analyzed (PJD). IFE´s general transportation process is visualized in figure 16.

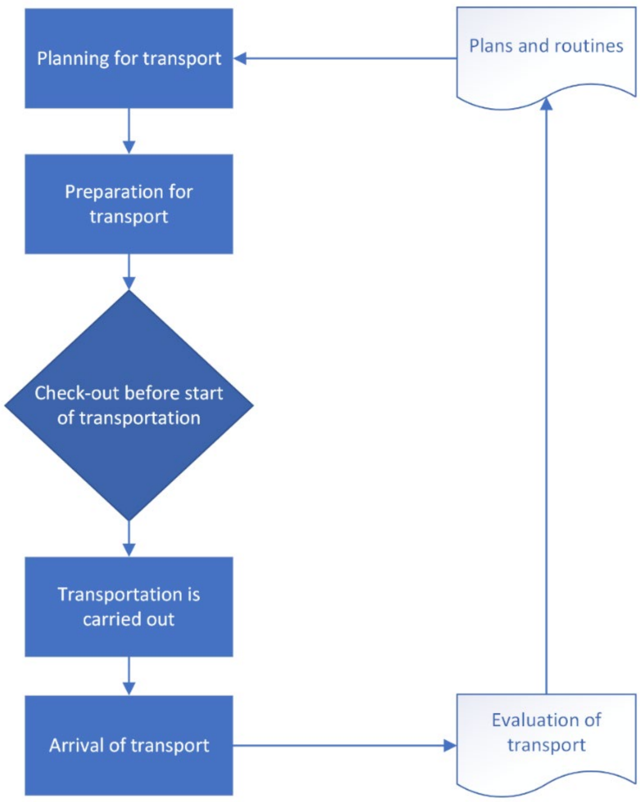

Figure 19. IFE´s process for transportation of radioactive waste.

8.1 International transports

Transportation of radioactive waste between countries is carried out by ship. When transporting to and from abroad, foreign containers are commonly used. These are certified by foreign authorities, and the certificates are validated by DSA. Four main transport types/routes are foreseen:

- Export of fresh fuel and heavy water for continued use in another facility.
- Irradiated nuclear fuel and experimental fuel to/from Studsvik/Sweden.
- Metallic LLW to Studsvik/Sweden for melting, and successive return of residues for disposal.
- Optionally spent fuel to/from Orano/France.

8.2 External transportation, between the Norwegian nuclear facilities

Transportation of radioactive waste between facilities is normally carried out by road or ship. Five main transport routes are foreseen:

- Spent fuel between Halden and Kjeller.
- Radioactive waste from external sources and from the Halden site to Kjeller
- Unconditioned waste packages to and from External service providers
- Unconditioned waste packages from Halden and Kjeller to the Interim storage
- Conditioned waste packages from the Interim storage to disposal

The ADR regulations set requirements for the robustness of waste containers and which external stresses they must be able to withstand. The ADR regulations also set restrictions on dose rates from the surface and up to 3 meters depending on the category of transport. All containers are marked on the outside [46].

ADR paragraph 4.1.9.1.12 states that the maximum dose rate at any external surface of a package or overpack under exclusive use shall not exceed 10 mSv/h [21]. Paragraph 4.1.9.2.1 states that the quantity of LSA-material (Low Specific Activity) and SCO (Surface-Contaminated Object) in a single Type IP-1 package, Type IP-2 package, Type IP-3 package, or object or collection of objects, whichever is appropriate, shall be so restricted that the external dose rate at 3 m from the unshielded material or object or collection of objects does not exceed 10 mSv/h.

Paragraph 4.1 in SAR chapter 7e for Kjeller states that in the case of special transports, the dose rate may be higher. In such a case, ROS must be performed for planned work tasks with this special transport / container [46].

All transports between Halden, Kjeller, conventional storages and the future interim storage, of both irradiated and unirradiated material, should be coordinated and controlled within the operating organization at NND.

8.3 Internal transportation

8.3.1. Kjeller

Internal transportation at Kjeller is carried out by forklift or with special transport vehicles in accordance with internal instructions. Barrels and boxes are transported to the Radwaste facility for measurement and treatment. Steel boxes and concrete molds are transported to storage building 2 for storage.

Radiation Protection personnel) controls waste packages that are produced internally at Kjeller and authorize transport to Radwaste [47].

8.3.2. Halden

Internal transportation in Halden will in firsthand be managed with a forklift. However, emptying of the reactor hall will partly be carried out through using the rail-wagon between the reactor hall and fuel bunker building. Transport to the new intended buildings and onto trucks for external transport will be carried out by forklift.

9. Waste containers

9.1 General

As far as possible the same container should be used through the whole chain of treatment, storage and disposal. This will minimize transferring of material as well as risk, time, dose and secondary waste used to clean containers etc. This means the choice of container must be well planned already from the dismantling, to fulfil transport requirements and radiation safety as well as the foreseen WAC for disposal.

A summary of all package containers used by IFE Halden is listed in the HBWR SAR-10, vedlegg 2 [48]. Radioactive waste containers should be labeled in accordance with paragraph 8.41 in [32]

9.2 The Swedish example regarding containers used for RW-disposal

For disposal of Swedish nuclear waste (VLLW-ILW) there are basically six different kinds of packaging:

Figure 20: Schematic illustration of waste packaging used or intended to be used in SFR (Sweden).

The picture shows the following packages:

- ISO 20 foot container full height (green)
- ISO 20 foot container half height (blue)
- Tetramold
- Steel mold
- Drum tray
- Steel drum
- Concrete tank/Steel tank
- Concrete mold

• Steel drums. Standard 200-litre drums. The dimensions differ slightly but the drums are approximately 90 cm high and have a diameter of 60 cm. In the ILW caverns and the silo, the drums are handled four by four on a steel plate or in a steel box. Both types are custom made for the system. In the IER waste-vault the drums are handled singly.

• Concrete molds. A concrete cube with the (out)side 1.2 m. The walls usually have a thickness of 10 cm, but can also be 25 cm. The molds are used for ILW-material and deposited in the ILW-disposal rock caverns. Some molds that contain low activity wastes are used to build stabilization walls in the disposals.

• Steel molds. Steel cubes with the same outer dimensions as the concrete molds, but with 5 or 6 mm thick walls. The steel molds can hold approximately 70% more waste than the concrete molds but offer considerably less radiation shielding. The steel molds are also deposited in the ILW-disposals.

• Concrete tanks. The tanks have the length of 3.3 m, width of 1.3 m and height of 2.3 m. The walls are 15 cm thick. The concrete tanks have a drain in the bottom of the tank. Concrete tanks are used in firsthand for ion exchange resins.

• ISO-containers. Standard containers, usually with the dimensions 6.1 × 2.5 × 1.3 m or 6.1 × 2.5 × 2.6 m, but other dimensions can also be used. The containers can hold drums, boxes or bales. There can also be no inner package, just piled scrap metal. The containers are used in the LLW rock caverns.

> Half-height 20 foot containers are used for concrete, both for solid concrete parts and for crushed concrete. The containers are filled up enough to prevent the contents from sliding around, however with a limit of maximum 20 tons per container.
>
> Full-height 20 foot containers are used for placement of Berglöf-boxes filled with LLW metal scrap. These containers are also used for light weight compressed insulation material.

• Steel boxes. These boxes are primarily used for intermediate storage of long-lived waste or inside the ISO-containers.

> Berglöf-boxes [24] are used during dismantling, treatment and clearance. It must be evaluated on a case by case basis whether to empty them into other boxes/bags/containers, or to load them into full-height containers for storage and disposal.

• Miscellaneous waste. Large components such as heat exchangers, large pieces from the biological shielding etc. could be disposed as they are.

Radiation related processes are judged to have no influence on the packaging.

9.3 Conditioning

Conditioning is those operations that produce a waste package suitable for handling, transport, storage and/or disposal. Final conditioning should be done immediately before disposal as this is the only way to meet successively changed requirements. NND plans to perform final conditioning at the future interim storage site, which will be planned and equipped for these measures.

Predictively the general type of conditioning of low level- and intermediate level wastes is to fill up casks with concrete to stabilize the containers, eliminate void, decrease solubility and bind loose contamination to delay release of radioactivity.

Conditioning is done according to WAC for the given disposal at the time of disposal.

10. Follow-up

NND waste handling is documented in the FLYT-system with regards to every certain piece of waste and its present location. The data in FLYT will specify e.g. material category, asset type, dose rate, used scaling factor and specific activity for each waste package. Lists of used material categories and asset types are appended to this report. From the system different statistics can be extracted for annual reports or computation of the throughput in different waste streams etc.

10.1 Work packages

Before a work package is started, NND will deliver a notice to DSA handling e.g. predicted risks and expected type and amount of waste material for the work package.

After the work package is finalized, NND will produce a report summarizing how much waste was produced totally and within different categories, as well as reasons for any deviations from predicted amounts.

10.2 Annual report

NND will report annually the amount of treated and deposited material according to the regulations given in [49].

11. Conclusions and recommendations

This WMP presents a concept for the future Norwegian nuclear waste management, from today through a number of phases to the final disposal. The report describes waste streams and facilities needed on existing sites as well as on the planned interim storage site and the future disposal facilities. Potential improvements of the current waste management activities at IFE have been identified, along with recommendations for the transition to a future waste management system.

The report gives a summary of how to differentiate waste into different categories and waste classes, how to treat different types of waste and how to arrange clearance of non-radioactive waste. The regulatory framework related to management of radioactive waste in Norway is also summarized.

The WMP concludes that both enhanced capacity in existing facilities and a number of new facilities are required to manage the future decommissioning of the Norwegian nuclear facilities. The pace of the decommissioning is strongly dependent on the availability of these facilities. New or enhanced storages is also an emphasized regulatory requirement to IFE regarding todays RW and SNF, independent from the future decommissioning. Licensing is always the most time-consuming task when developing new nuclear facilities. Thus, the licensing of these facilities should be of highest priority for NND and IFE.

- The report shows that only a minor part of the waste need treatment, storage and/or disposal.
- Elaboration of a new procedure for clearance of waste is fundamental to reach desired goals and a very important step for the decommissioning. It should be elaborated by IFE and NND in cooperation, with guidance from DSA. This work should be started as soon as possible.
- A more thorough characterization is required to verify the waste amounts and characteristics elaborated in the MOA-report. NND should emphasize the importance of the characterization work and IFE's participation in that work.
- An evaluation should be made of whether enhanced water treatment capacity is required in Halden, and, if so, how it can be achieved.
- An evaluation of the possibility to use existing buildings on the Kjeller site for waste storage purposes should be started.
- An evaluation of the possibility, costs and benefits of using space or existing buildings on the Saugbrugs area, compared to another area near Halden, for waste storage purposes should be started.
- Work on the siting of a new Interim storage as well as a National disposal facility should be started.
- The desired pace of decommissioning is a decision that affects the needed treatment capacity and thereby size and capacity of needed facilities.
- WAC for storage and transport should be developed, using international practice as a basis. These will be further developed when more information is available on sites, facility concepts and waste packages.

Conclusively this WMP is a conceptual document. It should be followed by basic design documents specifying volumes, capacities, storage sizes, shielding requirements etc. After that the detail design phase follows, specifying dimensions etc. These further steps point to the importance of Requirements Management, which should be implemented as the basis for the whole program.

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Attachment 1

Material categories used in FLYT (ch. 4.5) (to be further elaborated)

1	Carbon steel
2	Stainless steel
3	Galvanized steel
4	Copper
5	Lead
6	Biologic shield-reinforcement
7	Other metals
8	Asphalt/bitumen
9	Wood
10	Paper
11	Plastics
12	Other organic materials
13	Concrete
14	Biologic shield-concrete
15	Epoxi mixed concrete
16	Concrete with Chrome (VI) content
17	Graphite
18	Soil
19	Plaster
20	Asbestos
21	Glass
22	Porcelain
23	Insulation
24	Electronic devices
25	Cables
26	Ion exchange resin (IER)
27	Oil
28	Chemicals
29	Water
30	Heavy water
31	Gasses
32	Others

Attachment 2

Asset types used in FLYT (ch. 4.5) (to be further elaborated)

1	Auto clave
2	Battery
3	Beams
4	Biologic shield
5	Cables
6	Coffin for fuel management
7	Construction mtrl
8	Containment sluice
9	Door
10	El motor
11	El motor forced cooling
12	El. cabinet
13	El. device
14	Filter
15	Fire detector
16	Grating floors
17	Heat-exchanger
18	Heavy Water
19	Insulation
20	Lining
21	Liquids
22	Mech.device
23	Pipe/component support
24	Pipes
25	Process eq.
26	Pump
27	Radiation protection
28	Rails
29	Reactor pile
30	Reactor tank
31	Resins
32	Sink / sump
33	Soil
34	Stairs/ladders
35	Tank
36	Valve
37	Ventilation
38	Water
39	Window

Attachment 3

Waste amounts according to the MOA Project Report [37], chapter 21.5.1, table 150-152.

Halden

	RWM Route										
Waste Type/ Sub-Type	Unknown [Ton]	Uncond. Clear [Ton]	Cond. Clear [Ton]	Easy To Deconta-minate [Ton]	Process as VLLW [Ton]	Process as LLW (KLDRA) [Ton]	Process as LLW (New) [Ton]	Process as ILW (New) [Ton]	Process for RWM by ESP [Ton]	Treatment of Active Effluents [Ton]	Total [Ton]
Components	40,0	28,0	55,1	11,9	0,0	0,0	419,3	252,9	40,0	0,0	847,2
Piping	0,0	25,3	0,5	2,7	0,0	0,0	6,5	10,5	2,1	0,0	47,5
Structural Steel	0,0	0,6	234,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	234,7
Ventilation	0,0	0,9	3,1	24,0	0,0	0,0	3,8	0,0	3,0	0,0	34,8
Cabling & Chutes	0,0	0,8	205,6	0,0	0,0	0,0	51,4	0,0	0,0	0,0	257,8
Reinforcement	0,0	0,0	139,1	0,0	0,0	0,0	0,0	22,8	0,0	0,0	161,9
Concrete	0,0	22 229,9	1 253,6	0,0	1 253,6	0,0	380,0	0,0	0,0	0,0	25 117,0
Soil	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Combustibles	0,0	0,0	100,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	100,0
Insulation	0,0	0,0	10,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	10,0
Heavy Water	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	18,2	18,2
Resin	0,0	2,0	0,0	0,0	0,0	0,0	0,0	0,0	7,0	0,0	9,0
Liquids	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,6	0,7
Other	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total:	**40,0**	**22 287,5**	**2 001,0**	**38,6**	**1 253,6**	**0,0**	**861,0**	**286,1**	**52,3**	**18,8**	**26 838,8**

Kjeller

	RWM Route										
Waste Type/ Sub-Type	Unknown [Ton]	Uncond. Clear [Ton]	Cond. Clear [Ton]	Easy To Deconta-minate [Ton]	Process as VLLW [Ton]	Process as LLW (KLDRA) [Ton]	Process as LLW (New) [Ton]	Process as ILW (New) [Ton]	Process for RWM by ESP [Ton]	Treatment of Active Effluents [Ton]	Total [Ton]
Components	19,3	46,6	82,6	26,9	0,0	0,0	100,3	160,4	24,8	0,0	460,8
Piping	0,0	25,2	8,5	2,6	0,0	0,0	13,6	3,7	2,1	0,0	55,6
Structural Steel	0,0	226,5	11,8	15,7	0,0	0,0	56,9	0,2	2,0	0,0	313,0
Ventilation	0,0	35,1	7,4	1,6	0,0	0,0	28,6	6,3	0,2	0,0	79,2
Cabling & Chutes	0,0	17,4	5,0	2,4	0,0	0,0	1,4	0,5	0,5	0,0	27,2
Reinforcement	0,0	857,7	0,0	0,0	0,0	0,0	12,0	8,1	0,0	0,0	877,8
Concrete	151,0	13 985,4	0,3	0,0	0,3	0,0	197,4	374,2	0,0	0,0	14 708,6
Soil	0,0	0,0	0,0	0,0	1 295,2	0,0	0,0	0,0	0,0	0,0	1 295,2
Combustibles	0,0	28,2	25,3	0,0	0,0	0,0	17,4	0,0	4,4	0,0	75,3
Insulation	0,0	2,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,5
Heavy Water	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	7,0	7,0
Resin	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,2
Liquids	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	17,2	68,8	86,0
Other	0,0	7,6	0,1	80,0	0,0	0,0	168,9	24,0	28,2	0,0	308,8
Total:	**170,3**	**15 232,2**	**141,0**	**129,1**	**1 295,5**	**0,0**	**596,4**	**577,4**	**79,5**	**75,8**	**18 297,2**

Total

	RWM Route										
Waste Type/ Sub-Type	Unknown [Ton]	Uncond. Clear [Ton]	Cond. Clear [Ton]	Easy To Deconta-minate [Ton]	Process as VLLW [Ton]	Process as LLW (KLDRA) [Ton]	Process as LLW (New) [Ton]	Process as ILW (New) [Ton]	Process for RWM by ESP [Ton]	Treatment of Active Effluents [Ton]	Total [Ton]
Components	59,3	74,6	137,6	38,8	0,0	0,0	519,6	413,3	64,8	0,0	1 308,0
Piping	0,0	50,5	8,9	5,3	0,0	0,0	20,1	14,2	4,2	0,0	103,1
Structural Steel	0,0	227,1	245,9	15,7	0,0	0,0	56,9	0,2	2,0	0,0	547,7
Ventilation	0,0	36,0	10,6	25,6	0,0	0,0	32,3	6,3	3,2	0,0	114,0
Cabling & Chutes	0,0	18,2	210,6	2,4	0,0	0,0	52,8	0,5	0,5	0,0	285,0
Reinforcement	0,0	857,7	139,1	0,0	0,0	0,0	12,0	30,9	0,0	0,0	1 039,7
Concrete	151,0	36 215,3	1 253,9	0,0	1 253,9	0,0	577,4	374,2	0,0	0,0	39 825,6
Soil	0,0	0,0	0,0	0,0	1 295,2	0,0	0,0	0,0	0,0	0,0	1 295,2
Combustibles	0,0	28,2	125,3	0,0	0,0	0,0	17,4	0,0	4,4	0,0	175,3
Insulation	0,0	2,5	10,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	12,5
Heavy Water	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	25,2	25,2
Resin	0,0	2,0	0,0	0,0	0,0	0,0	0,0	0,0	7,2	0,0	9,2
Liquids	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	17,3	69,4	86,7
Other	0,0	7,6	0,1	80,0	0,0	0,0	168,9	24,0	28,2	0,0	308,8
Total:	**210,3**	**37 519,7**	**2 142,0**	**167,7**	**2 549,1**	**0,0**	**1 457,4**	**863,5**	**131,7**	**94,6**	**45 136,0**