Strategic Aspects on Waste Management in Decommissioning – 17224

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ABSTRACT

A team composed of the facility owner Oskarshamns Kraftgrupp AB (OKG) specialists and external experts was appointed to develop a basis for decision on an overall strategy for the management of the material and waste arising from the decommissioning of two BWR NPPs at the Oskarshamn site in Sweden.

To be able to provide a good basis for decision the full waste management chain from generation to disposition had to be assessed, categorized, quantified and analysed with regards to costs, environmental impact and risks.

A systematic approach was applied taking benefit of the existing decommissioning studies, well recognized decommissioning concepts and the combined knowledge and experience in the project team.

In total four different waste management concepts were compared individually and in combinations.

This paper discusses the important aspects in the work to develop a state of the art waste management in decommissioning. It also contains reflections and gives certain recommendations for decommissioning planning in general as well as an overview of some specific findings, results and recommendations from the actual project at Oskarshamn.

INTRODUCTION

OKG owns and operate the three units at Oskarshamn NPP, all boiling water reactors (BWR) of ASEA-ATOM design (today Westinghouse Electric Sweden). Unit one will be permanently shut down in summer 2017 and unit two will not restart after its modernization program, whilst unit three are planned to operate until 2045. Unit one and two are/will be taken out of operation earlier than initially planned due to current market situation. The OKG preliminary strategy is to perform an immediate dismantling. Since unit 2 have been under an extensive modernisation program most of the replaced components are likely subject to direct clearance.

The latest decommissioning planning activities are described in [1]. Decommissioning planning activities have been started up since long and the result of preliminary studies have been published by Swedish Nuclear Fuel and Waste Management Co (SKB) in for example [2].

In early 2016 OKG decided to perform a waste management strategy investigation aiming to form a decision base for the global approach regarding the management of the materials and wastes generated during the decommissioning of the two BWR plants. The investigation should cover all material and waste to be removed during the decommissioning i.e. everything from material with extremely low risk for contamination up to the reactor internals.

The study should clarify the handling procedures for all waste categories and make an evaluation of the different management and treatment concepts from a technical, environmental and economical perspective. It is a regulatory requirement (SSMFS 2008:1 chapter 6 [3]) that the waste management and disposition of the waste should be optimised.

The input data were taken from the previous decommissioning studies [2], data from performed power upgrade and modernization programs as well as data specifically gathered as evidence base for the investigation.

It was highlighted in the task description that the strategy for the management of materials and waste forms a foundation for all other strategies i.e. a waste led decommissioning. The development of an overall waste management strategy was therefore the first critical task in the strategic planning. Using a Waste Led Decommissioning approach this work has set the scene for the further strategic and overall decommissioning planning.

WASTE LED DECOMMISSIONING

Most licensees of nuclear facilities consider the management of the radioactive or potentially radioactive waste to be one of the most critical aspects of their decommissioning planning or ongoing decommissioning activities. One commonly adapted approach to reduce the risks related to waste management is to perform a Waste Led Decommissioning (WLD).

A key principle in WLD is that it is mandatory with a plan for the materials and waste prior to any dismantlement and demolition activities. A frequent and fast removal of material and waste will increase the performance in the decommissioning project. A weak waste management drives indirect and hidden costs.

WLD has also zero tolerance for waste streams without defined and accepted disposition route. Reconditioning is expensive and by applying WLD the chances to make it right the first time will increase significantly.

All radioactive and potentially radioactive materials and waste must immediately be registered in accordance with a defined procedure. There should be quality assurance and traceability throughout the process up to disposition (confirmed end-state).

Even though WLD put high demand on the Material and Waste Management it is fully possible and proven that WLD can be implemented without making the material and waste management a limiting factor during dismantlement and demolition.

METHODOLOGY

A methodology used for waste management strategies can be described as shown in figure 1 below. The two first steps are to define "the journey". Where it should end and from where are we travelling.

The third step is to define and describe the alternative Waste Routes and the fourth to make an evaluation of the alternative routes.

The fifth step, which needs a lot of attention, is to make a risk analysis covering several important aspects.

The final step is to draw out conclusions from step 4 and 5 and to give a recommendation for Waste Management Strategy.

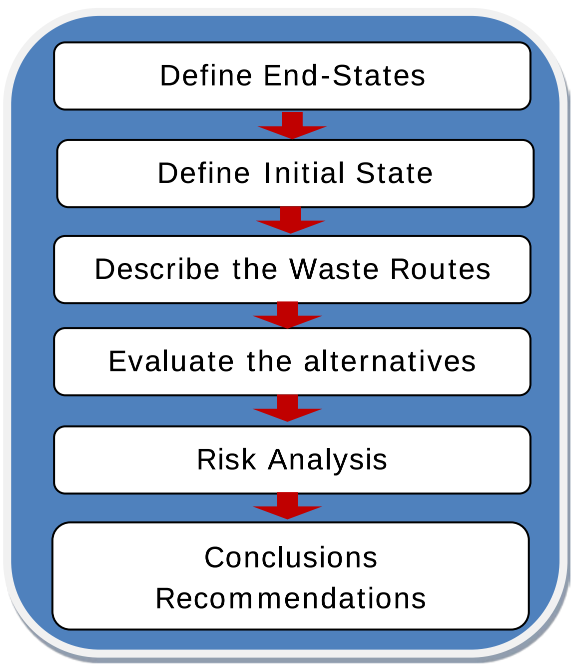

Figure 1: The applied Waste Management Strategy process.

Step 1: Alternative End-States

There are several possible End States for decommissioning waste. The different alternatives can be classified as clearance or disposal as radioactive waste.

Clearance

Two types of clearance exists – general and conditional. Clearance can be for Reuse, Recycling and Disposal as conventional waste.

General Clearance, or clearance for free use, means that material and waste can be reused, recycled or deposited without any radiological characteristics need to be taken into account.

Waste which may be subject to Conditional Clearance in accordance with special conditions may be concrete and sand recycled for road construction, metal recycled to the metal industry or waste to be disposed of on a hazardous waste disposal site. This type of clearance typically requires that certain conditions stipulated in the regulations are fulfilled or a special permit by the regulator with conditions is received.

Disposal as radioactive waste

Different disposal options are used worldwide. The once typically analysed options are disposal on site, in local surface repositories owned and managed locally or in central repositories provided by a national Waste Management Organisation.

Repositories are either existing (with formally approved WAC), in design or construction phase (normally preliminary WAC available) or planned (normally no detailed WAC available).

Step 2: Definition of Initial State

To be able to make a waste strategy it is important to understand the initial state of the facility to be decommissioned as well as the boundaries of the project. The later is fairly simple for a site to be entirely decommissioned while it can be complex when certain installations and buildings will remain.

Typically the first version of the waste management strategy will be developed prior to the overall characterisation campaign. To have a stable foundation for the WMS it is important to take benefit of operational history and the available characterisation information. The more you know – the better.

A key activity is the initial categorisation of the materials, buildings and site areas from a radiological and hazardous perspective as well as estimate volumes and masses. The most important decision is the decision where the “radiological fence” is placed. An example of how to categorize from a radiological perspective is given in table 1.

Strategic decisions on large components should be done as they have a massive impact on the WMS.

Table 1: Categorisation parameters for Swedish conditions.

Waste category	Specific activity content [Bq/g Co-60]
Extremely low risk	Contamination **cannot** occur
Low risk	Contamination of significance for clearance **should not** occur
Risk	< 0,1
LLW-1	0.1 – 1
LLW-2	1 – 20
LLW-3	20 – 100
LLW-4	100 – 1 000
ILW	> 1 000

Step 3: Description of the alternative Waste Routes
The alternative waste routes have to be identified and analysed for all categories except outside the radiological fence.

Typical waste routes can be:

- Dispose waste as is after dismantling i.e. no treatment
- Local waste treatment centre inside facility
- Local waste treatment centre outside facility but on site
- Ship to dedicated external waste treatment facility

Dispose waste as is after dismantling will only require space for segmentation to fit into waste containers and for conditioning of the waste packages. On the other hand direct disposal will generate large waste volumes for disposal.

A low investment cost alternative is to establish a local waste treatment centre inside the facility to be decommissioned (for example in the turbine hall). The challenge is to manage the logistics and the decommissioning schedule.

A fairly costly but attractive alternative is to build a new local waste treatment centre outside facility but on site. The big advantage is that it has a minimum impact on dismantling process. Despite the investment it is important to remember that a new decommissioning object is constructed.

For most countries it is possible to ship radioactive waste to a dedicated external waste treatment facility for treatment. It is partly transfer of risk and it usually provides significant reduction of volume for disposal. The treatment cost can be higher than for local treatment but should be balanced with less investments for local treatment and storage, less volume for disposal as well as less need for building competence in waste treatment.

Step 4: Economic evaluation of the alternatives
In many projects the evaluation of the alternatives is about direct costs and costs for investments in facilities and equipment. For a proper evaluation also indirect costs (including estimate of hidden costs) should be estimated as well as investments in competence, utilisation of waste management organisation and not at least the impact on project schedule.

Step 5: Risk Analysis
The Risk Analysis needs to cover several topics. Some of them are listed below.

<u>Uncertainties</u>
Known Knowns (no/low uncertainty)
Known Unknowns (possible to quantify)
Unknown Unknowns (impossible to quantify)
Reduced by additional characterisation activities of Known Unknowns
Mitigated by wider acceptance window for treatment/disposition

<u>Practical</u>
Availability of waste routes and disposition alternatives
Efficiency in processes
Where and how to recondition prior to future disposal, if needed
Reduced by keeping at least two waste routes and disposition alternatives open

<u>Financial</u>
Long term financial uncertainties
Reduced by applying clearance/direct disposal where applicable
Mitigated by transfer of risk

<u>Regulatory</u>
Uncertainties in current regulatory framework and potential future changes
Reduced by applying clearance/direct disposal where applicable
Mitigated by good communication with regulators

<u>Stakeholder relations</u>
Acceptance for clearance vs. disposal of recyclable material
Public view on extension of surface repositories on sites
Reduced by early involvement by stakeholders
Mitigated by quality assurance and short processes to end-state

Step 6: Conclusions and Recommendations
Draw conclusions in a helicopter perspective
Consider indirect and hidden costs
Secure that recommended concept does not promote a silo mentality in organisation – focus should be on total decommissioning cost (including waste

disposal)
Keep more than one route open where possible – do not put all eggs...
Give recommendations on Risk Reduction

RESULTS

Step 1: Alternative End-States

Initially several end-states were listed. After a screening process the following four end-states remained for eh project:

- General clearance as per regulation
  General clearance as per SSMFS 2011:2 [4] applying clearance levels for free use. The clearance limit for Co-60 is 0.1 Bq/g.

- Conditional clearance as per regulation or special permit
  Conditional clearance as per SSMFS 2011:2 [4] applying clearance levels for hazardous waste. The clearance limit for Co-60 is 1 Bq/g.

  Conditional clearance of metal ingots as per license based EC recommendation RP 89 [5]. The clearance limit for Co-60 is 1 Bq/g. Decay storage of ingots for up to 25 years prior to clearance is accepted for Swedish material.

- Disposal in VLLW surface repository on site
  A surface repository on site for waste with a dose rate lower than 0.5 mSv/h and which meet the requirements on nuclide specific emissions. Both compactable and non-compactable waste can be deposited in this repository after a routine assessment and measurement. Such repository licensed for operational waste is existing on site. See figure 1.

Fig.1. OKG surface repository disposal campaign.

- Disposal in geological repository
  The Swedish program on nuclear waste include a geological repository for low and intermediate level nuclear waste (SFR) as well as the repository for long-lived low-and intermediate-level nuclear waste (SFL). The SFR has to be extended for decommissioning waste. The extended SFR is forecasted to be taken into operation in the early 2030’s why the waste will have to be stored up to then. Waste Acceptance Criteria for the extended SFR are not yet available. SFL will be commissioned 2045 as per current schedule.

  The extended SFR is illustrated in Figure 2. The existing part is to the right (1BMA, 1BLA, 1+2BTF, Silo) and the planned extension to the left.

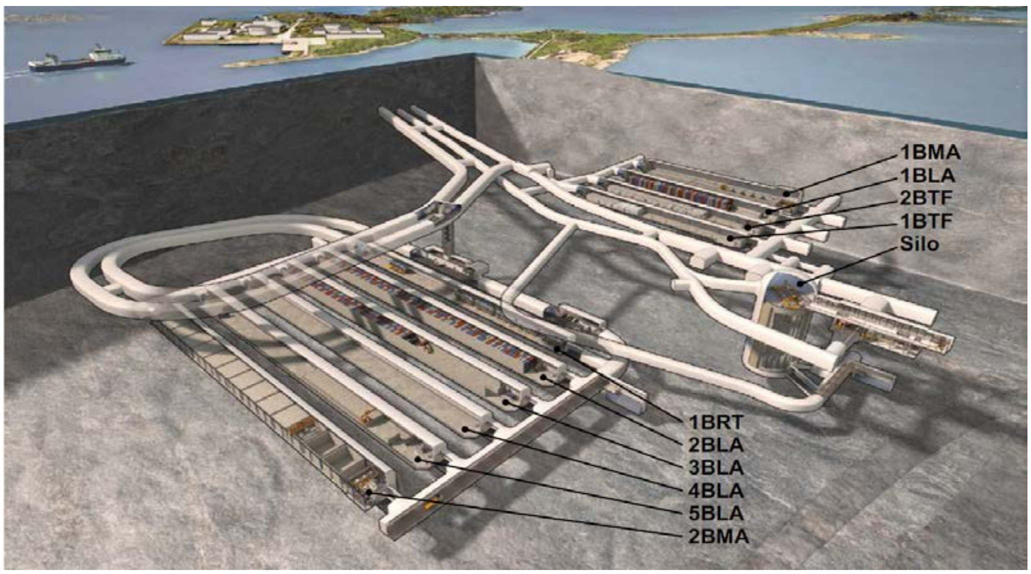

Fig.2. SFR repository after extension. (Source SKB [6])

Step 2: Initial State

Taking benefit of the decommissioning studies, operational records and a lot of other relevant information the materials and waste expected to be generated during the decommissioning was categorized and quantified.

For each category quantification was performed per material type and category. Table 2 is a summary of the masses of waste in each category.

Table 2. Amount of waste per category.

Waste category	**Total [Mg]**
Extremely low risk	221 400
Low risk	Not quantified
Risk	11 400
LLW-1	6 540
LLW-2	1 350
LLW-3	997
LLW-4	1 805
ILW	2 440
Total	246 237

The mass distribution of the LLW waste (LLW 1-4) is expected to be as per figure 3.

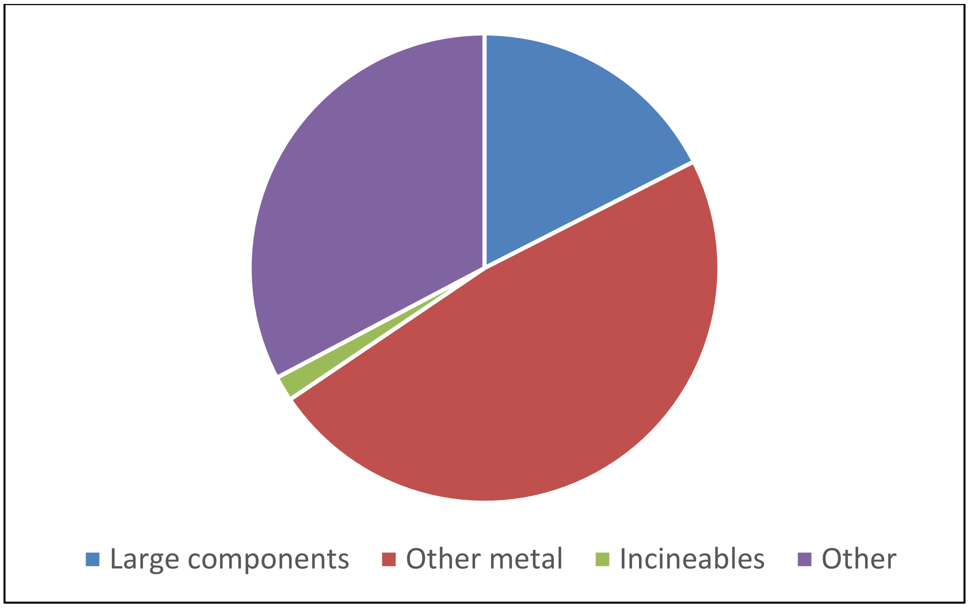

Fig.3. Composition of the Low Level Waste from the decommissioning.

Step 3: Alternative Waste Routes
Four waste routes were selected to be analysed in a waste management perspective. The principles and conclusions are summarized below.

Geological disposal without treatment

- Materials which in a very easy way can be free released will undergo general clearance locally.
- Major components are sent for external processing at Studsvik site.
- All other waste with the exception of major components will be conditioned for deposit in a geological repository.

Since SFR not is expected to be available during the demolition and decommissioning all the material need to be placed in an interim storage for about a decade. Provided that the intermediate storage will not affect the dismantling and demolition process this waste route is considered to be a time efficient option from a decommissioning and demolition purposes.

Off-site treatment for volume reduction or clearance

- Materials which in a very easy way can be free released will undergo general clearance locally.
- All other material, except for things that can't be processed for conditional clearance or volume reduction, is sent to the waste treatment facilities at the Studsvik site for processing.
- Residual waste produced is stored at Studsvik site up to final disposal in SFR.

This route has high level of clearance and recycling. Provided that frequent transports can be arranged, this is considered to be the most time efficient option from a decommissioning and demolition perspective as the time from dismantling to the waste leaves the decommissioning area is short.

Local clearance in a dedicated facility

- Applicable on Low risk, Risk and potentially LLW-1 only.
- Focus on clearance of materials either directly or after decontamination.

Requires significant investment in a decontamination and clearance facility within the existing buildings or elsewhere within the organisation. This option will have a high degree of clearance and recycling but may also have a significant negative impact on the schedule.

Surface repository on site without treatment

- Materials which in a very easy way can be free released will undergo clearance locally.
- Large components are not allowed in surface disposal and will there for be sent externally for treatment.
- All other material up to 0.5 mSv/h, which complies with the requirements of the nuclide specific limit values, are disposed here.
- The remaining nuclear waste will be conditioned and disposed in SFR.

Provided that the surface repository can be made available for decommissioning waste, this is a time-efficient option.

Step 4: Economic evaluation of the alternatives
In this step the different costs for the estimated amount of waste for each waste category and end-state were calculated for each of the available alternatives. Some waste streams, mainly ILW, has only one possible waste route. Other waste streams have up to four alternative waste routes

Table 3 indicates the calculated costs, based on available information and performed estimates, for the different waste types and routes calculated as direct costs or the cost for one additional tonne to an existing waste route i.e. without investments in facilities, administrative organisation etc. The numbers in the table are for the two alternatives lowest in cost. The maximum value only applies if more than two alternatives were available. It must be noted that the purpose of this exercise was to get an understanding of the cost level for the different routes. Uncertainties related to estimates of volumes and categorisation were not analysed.

The calculations indicated that none of the four waste routes were among top two for all waste streams but all waste routes were in top two for at least a few waste categories.

For the category Low Risk (which is not included in Table 3 as the volumes not have been quantified) the Local Clearance waste route seems to be the preferred alternative. The same applies to "Other Waste" in category Risk.

For the highest category (ILW) geological disposal is expected to be the only option.

Table 3. Estimated costs for management of the waste (MSEK).

Waste category	Large components	Other metal	Incinerables	Other
Risk	113-150 ()	186-221 (max 401)	2-4 (max 7)	No info
LLW-1	30-32 (max 42)	90-106 (max 206)	2-3 (max 7)	19-40 (max 70)
LLW-2	25-26 (max 35)	9-12 (max 21)	1-2 (max 5)	6-11 (max 19)
LLW-3	21-22 ()	7-10 (max 12)	1-2 (max 5)	2-4 ()
LLW-4	6-12 ()	28-34 ()	0.4-1 ()	50
ILW	107	82	1	73

Remark: () = only two alternatives available, numbers without span indicates that only one alternative is available.

In Figure 4 is the distribution of costs between the four overall waste types for LLW illustrated.

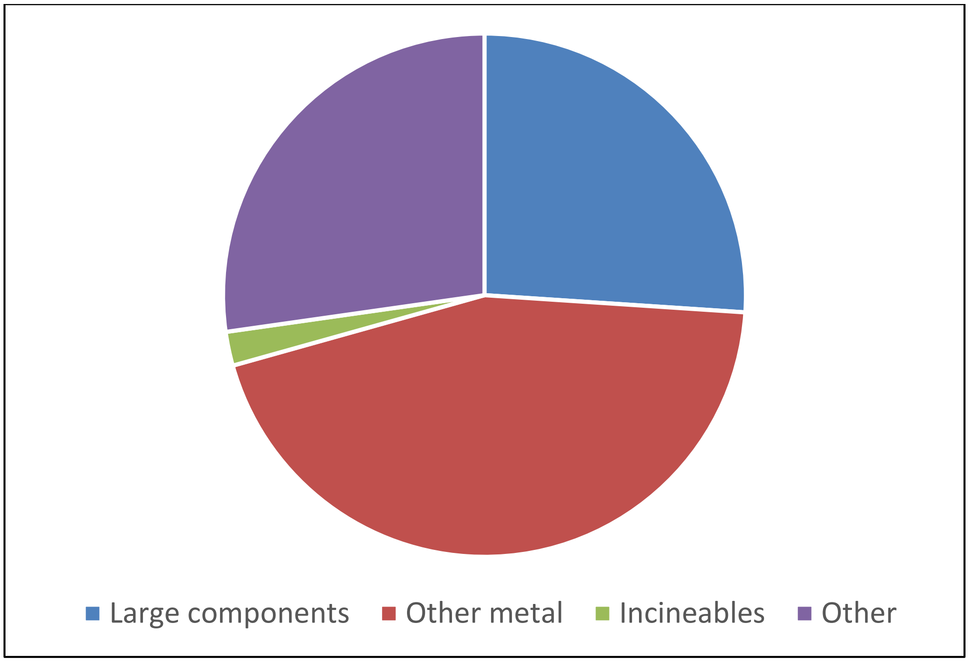

Fig.4. Estimated distribution of costs for Low Level Waste

The required investments are estimated to vary up to a factor 2 depending on selection of waste route(s) and are in total in the order of MSEK 100. The major differentiator is related to how advanced facility that will be needed for decontamination and clearance of waste and material on site.

Step 5: Risk Analysis

Upon completion of the cost evaluation a risk assessment was performed. The methodology described above was used. The findings were recorded as per table 4. The table includes a few examples taken from the result.

In addition to the analysis of overall risks the four different waste routes were analysed, cost impact estimated and potential mitigation activities proposed.

Table 4. Table for risk analysis result with examples.

Risk description	Probability (low, medium, high)	Consequence	Cost impact (low, medium, high)	Mitigation to reduce risk
Poor characterisation/ categorisation of radiological and non-radiological properties	L-M	Additional efforts which delays the project	L-H	Secure robust processes, quality assurance
Non clearable waste to clearance station	H	Re-routing of waste. Failure investigation	L	Education, Quality assurance
New requirements for final disposal of waste	M	Opening of waste packages, additional sampling	L-M	Reversibility, precaution measures
		Reconditioning	M-H	Dialogue with repository owner

DISCUSSION

The large majority of the radioactive waste arising during the decommissioning process is expected to be metals. Based on international experience there is a risk that the waste type named “Other Waste”, i.e. contaminated concrete and other structural material, categorized as LLW may be underestimated. An increased clarity on this topic will follow after the facility characterisation project.

It is positive that there are alternative waste routes for most of the waste. Considering the risks related to logistics and exit/disposition of the waste there is a significant value of keeping more than one route available during the decommissioning process. The value is hard to quantify but it is well known that one of the most important targets for a decommissioning project is to keep the schedule.

Based on cost, risk and environmental impact the different waste routes have different advantages and disadvantages related to the specific type and category of waste. Redundancy by keeping two or sometimes three waste routes available is considered Good Practice by the involved experts. Drivers for redundancy vary between waste categories based on logistics, financials and/or risks.

Environmental impact aspects in decommissioning are very important for the stakeholder relations and to give evidence for the sustainability of nuclear power.

Clearance and recycling is considered as good practice. The study shows that routes with a high degree of clearance and recycling are equal and in some cases lower in cost.

As indicated above it is considered important to keep focus on the total decommissioning cost, including waste disposal. Uncertainties related to waste disposition must not be underestimated and should be mitigated to the extent practically possible. Inadequacy in the waste management chain drives both direct and indirect costs and directly affects the time schedule.

CONCLUSION

The study shows that the estimated cost for the recommended approach based on a combination of the two most cost efficient waste routes, is approximately 20 % less expensive than the reference alternative based on geological disposal.
By choosing the cheapest available route for the different streams and categories an additional 5 % can be saved.

Taking the risks in waste management and in the overall decommissioning project into consideration, the additional cost for applying redundant waste routes is considered a reasonable, or even cheap, risk mitigation fee.

Thus redundancy in waste streams is considered as Good Practice for the actual project.

The recommendation by the group of experts conducting the study taking available technical, economic, environmental and risk parameters into account is a split into all four waste routes as per Figure 5. It must be noted that the material and waste category Low Risk which requires clearance and Risk for waste type Other Waste not yet has been quantified. A large percentage of this waste will most likely be subject to local clearance i.e. the percentage of local clearance will most likely increase significantly.

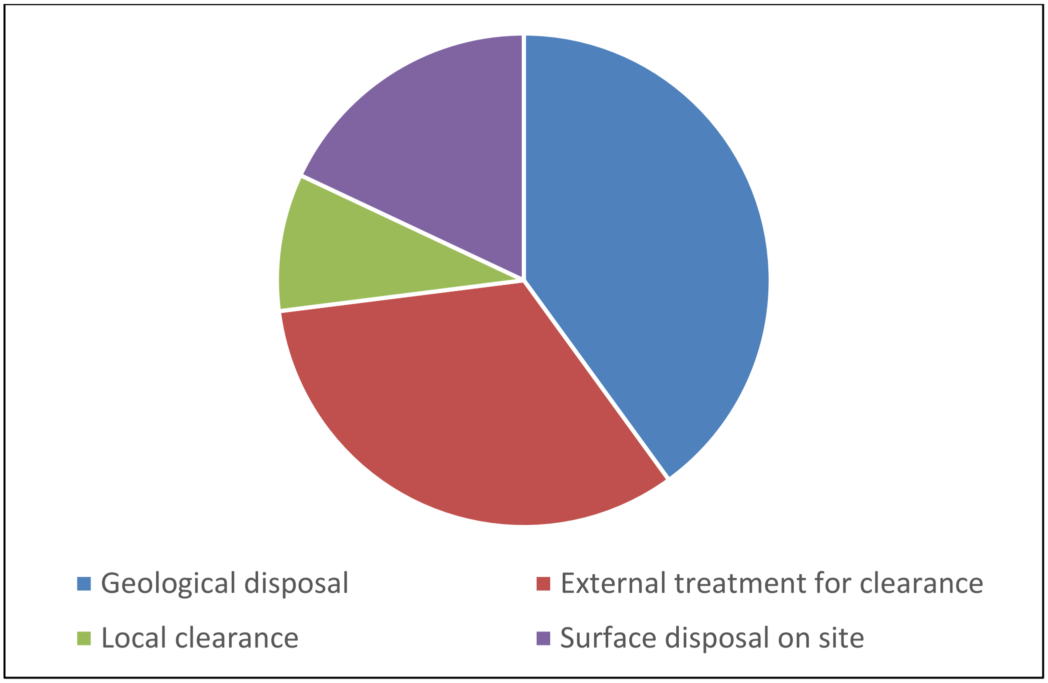

Fig.5. Recommended distribution on the different waste routes (MSEK).

Following the waste led decommissioning planning concept the waste and material strategy study was the first of a series of activities to develop and implement the strategies for the decommissioning project. Proposed continuation consists of iterative update of the study report as the characterization process progress.

The waste and material strategy report represents a baseline for the waste and material logistics, and further on also for planning the dismantling sequences. This overall planning sequence makes it possible to identify bottlenecks and mitigate risks in the waste management chain and for the entire decommissioning project at an early stage of the planning process.

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