SKI Report 2004:11

Research

An Applied Study of the Storage for Old Intermediate Level Waste at the Studsvik Site

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SKi

SKI perspective

Background

The nuclear power utilities must under the so-called Studsvik Act (the complete name is the Act on the Financing of the Management of Certain Radioactive Waste etc. (1988:1597)) contribute with 0,15 öre (approximately 0,02 cents) per kWh produced by nuclear power to the Swedish Nuclear Waste Fund. This part of the financing system was decided by the Swedish parliament for covering the expenses for the decontamination and decommissioning of older Swedish research reactors. The task to inject appropriate capital to the Swedish Nuclear Waste Fund is crucial for the sustainability of this financing system. Therefore it is highly important that provision to the fund reflects the actual costs of performing the planned and described tasks in the future.

Purpose of the project

The primary aim of this applied study has been to describe the context of cost estimation for decontamination and decommission of the storage for Old Intermediate Level Waste (hereafter denoted AT from Swedish "det Aktiva Tråget").

Moreover, SKI´s standpoint is that all measures that enhance the overall quality of the calculation of fees to the fund are essential research tasks if the studied object or cost item has a significant impact on the funding done under the Studsvik Act.

Results

The study demonstrates that it is possible to enhance and extend the present knowledge basis for cost estimates by using feedback of experience. By defining the level of contamination, exploring possible new methods that can be applied and finding a similar object for benchmarking purposes, it will be possible to improve the reliability of cost calculations. The report is to be seen as part of an active learning process; that ultimately may help us to improve calculations so that a reliable estimate of the decontamination and decommissioning cost can be made at a confidence level of at least 80 %.

The study clearly illustrates that the task of finding appropriate cost estimates may have to start with radiological mapping at the particular facility. By adopting this approach, sufficient information may be obtained in order to carryout an efficient technical planning. In the planning process it may also be appropriate to include a presentation of different available modes of methodology.

Finally, the applied study also demonstrates an alternative context for how to develop reliable and sustainable estimates of cost for decontamination and decommission. It ought to be stressed however, that this is one of many examples of how the present procedure may be developed.

Continued work

This study indicates that there is a need to develop a more comprehensive platform of decommissioning cost information and interpretation in order to give an increased future understanding of the prerequisites for prudent cost estimations as well as the sequence by which reliable cost estimates can be compiled. The next step in this process would be to identify “a sister-object” to the AT for cost comparison and benchmarking purposes. By comparative cost studies an indicative and indirect validation of the estimated cost for decontamination and decommission of a particular item will be possible.

Effects on SKI work

SKI will be able to draw inferences from this study in the ongoing monitoring of yearly cost estimates that are presented by the company AB SVAFO. Thus, the study will therefore support the present review process regarding estimated dismantling costs of the AT located at the Studsvik site.

Project information

At SKI Staffan Lindskog has been responsible for supervising and co-ordinating the project. Rolf Sjöblom at TEKEDO AB has been responsible for the information gathering analyses as well as the disposition of the report.

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SUMMARY

The Storage for Old Intermediate Level Waste (SOILW) at Studsvik has been used for interim storage of intermediate and high level radioactive waste from various activities at the Studsvik site including post irradiation investigations. The SOILW facility was in operation during the years 1961 – 1984. The waste was stored in tube positions in concrete blocks and in concrete vaults.

In some instances, radioactive debris and liquid has contaminated the storage positions as well as the underlying ventilation space.

The primary purpose of the present work is to improve and extend the present knowledge basis for cost estimates for decommissioning, with the ACSF facility as an example.

The main objective has been to explore the possibilities to improve the reliability and accuracy of capital budgeting for decommissioning costs at SOILW.

In this study, the present international status of decommissioning, planning and cost estimation has been compiled.

The various relevant guidance documents of the IAEA are also compiled, and their emphasis on the necessity of radiological and other surveying as well as technical planning and method selection is reiterated.

Cost calculation schemes for new plants and for decommissioning are compiled. It is emphasized that the calculations should be carried out differently at different stages. At the early stages of decommissioning, there should be more emphasis on comparison, and at later stages the emphasis should be more oriented towards summation.

The error/uncertainty in a cost calculation is strongly dependent on the selection of methodology, which, in turn, is strongly dependent on the radiological condition.

The magnitude of the level of uncertainty has been illustrated by the example of concrete surface removal, and advice is provided on how to identify alternative measures that will enable more sure decisions.

An example is also given on a rather similar decontamination and dismantling involving highly contaminated tubes in a concrete block. The experience includes drilling through contamination and penetration of voids.

The conclusion of the report is that tools are available for rather precise calculation of costs. This presupposes that radiological characterisation ought to be made as well as technical planning before any firm statement can be made about the accuracy of the estimates of the decommissioning costs.

1 BACKGROUND

1.1 The Storage for Old Intermediate Level Waste (SOILW)

The Storage for Old Intermediate Level Waste (SOILW, "Aktiva Tråget" or AT in Swedish) has a main history as follows:

1960	Start of construction
1961	Start of operation including storage of waste
1970	Start of construction for extension
1971	Start of operation of the extension
1984	Waste emplacement discontinued
1987	Start of removal of waste
2001	All waste removed

SOILW has been used for interim storage of intermediate and high level radioactive waste from various activities at the Studsvik site, including test reactor and hot cell laboratory operation. Some of the waste came from outside Studsvik, e g the Swedish Military.

Much of the high level waste originated from fuel tests and subsequent post irradiation investigations. It comprised fuel debris and in some cases also slurry used for polishing of specimens. The material was packed in tins made from sheet metal.

The SOILW comprised a number of storage compartments of two kinds, concrete blocks with vertical pipes for storage of tins as just described and compartments with no internal structures for storage of intermediate level waste of various kinds.

At the bottom, the vertical pipes enter into a ventilation area, which is about 5 – 10 centimetres high.

All storage compartments have thick concrete lids for radiation shielding.

The facility has been emptied from radioactive waste but not cleaned. Significant levels of contamination are believed to exist on the surfaces of the vertical pipes and at the bottoms of the compartments.

The exact time for the decommissioning may depend on the outcome of the radiological survey as well as the technological prerequisites.

Costs have been estimated for a full decontamination and decommissioning at the cost level of the year 2001 [1] and the result is a total of 75 MSEK comprising the following parts:

- Preparation, follow up and closing activities of the planning project group — 7,4 MSEK
- Fees* together with planning and procurement — 36,4 MSEK

- The actual decontamination and decommissioning** work 30,8 MSEK

* the fees for SFL (final storage for long-lived waste) amount to 20,8[1] MSEK
** the dismantling of the pipe positions amount to 14,0 MSEK

1.2 The system for financing

Substantial development work was carried out in conjunction with the introduction of nuclear power in Sweden, and much of it took place in the facilities at the Studsvik site. Consequently, it has been decided that it is those who benefit from the electricity generated by the nuclear power plants who shall pay the costs for the decommissioning, decontamination, dismantling and waste management which is required when the facilities at Studsvik are no longer needed.

Thus, the *Law on financing of the management of certain radioactive waste e t c*[2] (SFS 1988:1597) states (§1) that *"fee shall be paid to the Government in accordance with this law as a cost contribution"* to amongst other things *"decontamination and decommissioning of"* … *"the Storage for Old Intermediate Level Waste (SOILW)"*.

The *Ordinance (SFS 1988:1598) on financing of the handling of certain radioactive waste e t c*[3] states (§4) that the funds collected should be paid to cover the costs incurred. It also states (§4) that *"payment will be carried out only for costs which are needed for"* the decontamination and commissioning *"and which have been included in the cost estimates"* required.

According to the *Law on financing of the management of certain radioactive waste e t c* (SFS 1988:1597, §5), cost calculations shall be submitted to the Swedish Nuclear Power Inspectorate (SKI)[4] each year. They shall comprise estimates of the total costs as well as the costs expected to be incurred in the future with special emphasis on the subsequent three years.

The Swedish Nuclear Power Inspectorate (SKI) has the responsibility (SFS 1988:1598, §5) to review the cost estimates and to report to the Government if there is a need to change the level of the fee. The SKI also has the responsibility (SFS 1988:1598, §4) to decide on the payments to be made.

It might be added that according to its instruction (SFS 1988:523, §2)[5] SKI also has the responsibility *"in particular … to take initiative to such …*

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1 At present (February 2004) this cost is 4,2 MSEK
2 In Swedish: *Lag om finansiering av hanteringen av visst radioaktivt avfall m. m.*
3 In Swedish: *Förordning om finansiering av hanteringen av visst radioaktivt avfall m. m.*
4 In Swedish: Statens Kärnkraftinspektion
5 *Ordinance (1988:523) with instructions for the Swedish Nuclear Power Inspectorate.* In Swedish: *Förordning (1988:523) med instruktion för statens kärnkraftinspektion.*

research which is needed in order for the Inspectorate to fulfil its obligations".

The legislation referred to above can be downloaded from SKI's website (www.ski.se) or from Rixlex (www.riksdagen.se/debatt/).

1.3 The planning for decommissioning

It is obvious from the preceding section that a solid prerequisite for the responsible management of the decommissioning of the various facilities concerned is that realistic cost estimates can be made.

Moreover, the estimates must be based on a sufficiently ambitious program to guarantee that all the pertinent requirements of the society are met. At the same time, unjustified fees should not be levied on the users of the nuclear electricity.

The issue is far from a trivial one. Not infrequently, cost estimates are raised by a factor of two for every new estimate, and such signs on tendencies have been encountered also in the presently discussed context.

Thus, high requirements apply to cost estimates as well as to the knowledge base on which they rely. In particular, there is a need to identify in what way feedback of experience might be utilised in order to achieve sufficiently robust estimates. The feedback should include the experience made so far in the domestic program as well as that made in relevant project internationally.

2. PURPOSE AND FRAMEWORK

2.1 Purpose

The primary purpose of the present work is to enhance and extend the present knowledge basis for cost estimates. A second purpose is to provide SKI with an independent basis for its annual review of the cost calculations submitted by AB SVAFO[6] no later than the last of April every year.

The main objective of the present work is to explore the possibilities to improve the reliability of cost calculations by feedback of experience. By the very nature of the issue, this relates primarily to developments of methodology for cost estimates and productivity evaluations. However, the cost issues are very intimately interlinked with the various aspects of technology, management and planning. Therefore, these issues are no less important.

The purpose is not to provide any advice to Studsvik or any other implementers on technical details[7]. However, in order for the results of an applied study to be realistic and relevant, it has to be concrete in part, cf the next section.

2.2 Framework – retrieval of information

The framework of the work is as follows:

1. To review the report *"SVAFO - Decommissioning studies of Studsvik facilities – store for historical waste, the Storage for Old Intermediate Level Waste (SOILW)"*[1], references therein and other related material at Studsvik.
2. To visit the facilities and meet with those responsible.
3. To carry out an information search on technical methods, including alternative approaches, with emphasis on cost-effective methods.
4. To carry out an information search on calculation for the type of activities in question.
5. To carry out an information search on feedback of experience, including post calculations, for activities in question, including the communication aspects.

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6 SVAFO is the purchasing organisation. It exists in order for a proper procurement – supplier situation to be maintained throughout. Presently, it is affiliated with Studsvik AB, but was formerly jointly owned by the four companies Forsmark Kraftgrupp Aktiebolag, OKG Aktiebolag, Barsebäck Kraft AB oh Ringhals AB.

7 Actually, any analyses made in the present report should be regarded only as examples of conceivable alternative approaches. Thus, the responsibility for the options actually identified and used rests entirely with the implementers.

2.3 The layout of the work and the structure of the present report

The actual work was carried out in two steps:

- Review of the report *"SVAFO - Decommissioning studies of Studsvik facilities – store for historical waste, the Storage for Old Intermediate Level Waste (SOILW)"*[1] and literature searches together with a first visit to Studsvik.
- Three additional visits to Studsvik together with surveying and analysis of the literature identified in the previous stage.

The interim results from the first stage were used to define the specific approach to be used in the second stage.

The discussions with the people at Studsvik and SVAFO have been most helpful throughout the work. Actually, this communication has been a prerequisite for a successful completion of the present work. Thus, the present authors wish to express their sincere gratitude to Carin Ehrs and Börje Johnsson at the Studsvik supplier side and to Robert Berg and Per Riggare[8] at SVAFO[9].

A summary of the material and impressions from Studsvik are compiled in Section 3.

For the structuring of the report it has been found feasible to differentiate between on one hand International Atomic Energy Agency[10] (IAEA) Safety Guides and on the other hand other documents. IAEA safety standards carry a very heavy weight among the nuclear communities. In Sweden, IAEA rules might for practical purposes be regarded as forming a "floor" for national legislation and regulation. Moreover, in the field of nuclear technology, IAEA rules, guides and recommendations pretty much play the role of norms and standards in other branches of industry[11].

Thus, material from IAEA sources is dealt with in Section 4, and material from sources separate from both Studsvik and the IAEA are dealt with in section 5.

The analysis and conclusions of the authors are given in section 6.

The literature surveyed in separated in two categories. Documents specifically referred to in the text are listed in section 7. Documents

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8 Now with the Swedish Nuclear Fuel and Waste Management Company.

9 See footnote 5.

10 An agency under the United Nations.

11 Actually, one basic role of norms and standards is to form a basis for the fulfilment of corresponding regulation, i. e national laws and ordinances in the areas of radiation protection and nuclear safety which, in turn, are based on EU agreements (especially *Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment* and *the Euratom Treaty {Article 31})* as well as recommendations from *The International Commission of Radiological Protection, ICRP*.

otherwise surveyed and found relevant are listed in section 8 in arbitrary order.

3 MATERIAL FROM STUDSVIK

3.1 The planning report

The identification, selection and establishment of suitable and appropriate schemes for decommissioning depend on the design of the plant together with the radiological situation.

A general introductory description of the design of the Storage for Old Intermediate Level Waste (SOILW, "Aktiva Tråget or AT in Swedish) was given in section 1.1 and will not be repeated here. This description is based on reference [1].

The account, which follows below, is based on other references as well [2-4].

The layout of the facility is shown in Figure 1. The figure also states the thickness' of the concrete blocks into which the vertical pipes are moulded.

The handling space above the compartments and the concrete lids is classified as "yellow" which implies that the surface contamination is between 40 and 1000 kBq/m^2 for beta plus gamma radiation and between 4 and 100 kBq/m^2 for alpha. The dose rates in the compartments with no internal structures are on the order of 0,5 mSv/h which is too high for work by man in situ (except possibly for very limited periods of time).

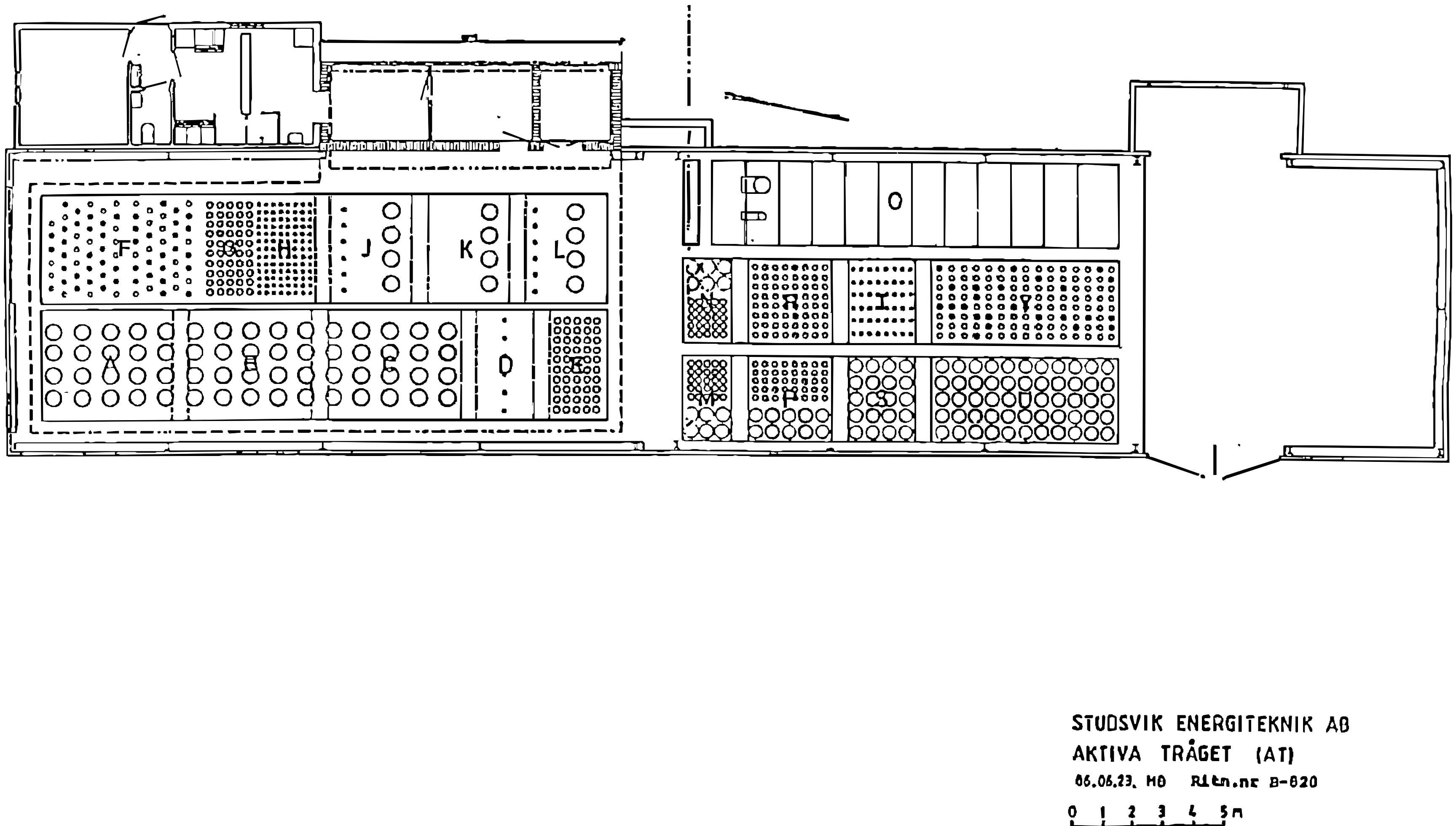
The dose rate in the pipes used for stacking tins is believed to be high, at least at certain locations. The reason is that the tins contained not only fuel debris but also liquid, supposedly absorbed in vermiculite, containing nitric acid which caused corrosion of the tins as well as leakage and contamination of the pipe shafts.

Also, it is known that small objects have dropped down to the ventilation area underneath and possibly caused contamination.

The procedures outlined in [1-2] are based on the assumptions that the insides of the vertical pipes are heavily contaminated by leakage from the cans containing the high level waste. Thus they need to be decontaminated. Some of the pipes are spirally welded (compartments G and H in Figure 1), but most are lock seamed (to a lap joint). It is not obvious from the report whether the seam is of the single or double fold type. It is assumed, however, that the pipes that have lock seams also have contamination in the seam or even on the outside surface.

All pipes are to be cleaned using carbon dioxide jets. It is assumed that all pipes having welds will become clean enough for unconditional release. However, it is also assumed that the pipes that have lock seams will not become completely clean in the seams (or on the outside).

Figure 1. *Layout of the Storage for Old Intermediate Level Waste (SOILW, "Aktiva Tråget or AT in Swedish) at Studsvik. Compartments A-D, J-L and O are "open" i e do not have any interior structures. Compartments E-H as well as M, N, P, R, S T, U and Y contain vertical pipes in concrete blocks. The blocks are 0,9 meters thick (high) for compartments G and H (but the pipes extend further down below the blocks). The blocks are about 3 meters thick for compartments E and F, and about 3,4 meters for the compartments M, N, P, R, S, T, U and Y. Details regarding compartments F and T have not been found.*



It is thus assumed that those pipes that have seams – which comprise the vast majority – need to be removed by core drilling (after decontamination on the inside). The drilling is to be made using a conventional drilling rig and water as coolant and lubricant.

It is assumed that this might not be particularly problematic since the concrete blocks and their surfaces are expected to be radiological clean.

It was mentioned in section 1.1 that there is a ventilation space of 5 – 10 centimetres between (most) concrete blocks having vertical pipes and the floor underneath. This area underneath is expected to hold surface contamination. Thus, any operation that may involve accessing this area (or having the potential for it) need special consideration.

It is anticipated [2] that some preliminary removal of specimens and vacuum cleaning in this area will take place as a first step. Then, plugs are inserted at the bottoms of the pipes, whereafter the decontamination is carried out of the insides of the pipes.

The core drilling is wet only to immediately before penetration, at which stage dry drilling is used instead.

Thoughout the operation, ventilation is intended to be maintained in accordance with the pattern used during operation. The ventilation area underneath is kept at a slight underpressure to limit the amount of contamination that might be carried to the area above the pipes. The air thus evacuated is to be cleaned by filtration.

After the vertical pipes have been removed – alternatively cleaned completely – the concrete blocks are to be size reduced into pieces which can be handled by the crane which is at most 10 tons.

It is anticipated that the surfaces of the concrete blocks be relatively clean at this stage. A positive factor in this regard is the fact that there is a steel sheet metal plate at the bottom of the blocks. This implies that it may be feasible to clean the bottom surfaces from whatever contamination they might have.

The breaking up of the blocks is intended to be made by means of drilling and mechanical fracturing.

A more detailed procedure for the core drilling can be found in [2], Appendix 6.

Once the blocks have been removed surfaces become accessible for (further) cleaning and for removal of the contaminated surfaces of concrete. Such cleaning and removal of surface material is also expected to be warranted for those compartment which did not have any interior structures.

It is assumed in the report that a surface layer of 3 centimetres will have to be removed. This corresponds to the generation of 63 cubic meters of concrete debris with a weight of 157 metric tonnes[12]. It should be noted that this is the compact volume and that the actual one is larger.

According to plan, the auxiliary systems will be dismantled with the approach of removing the most contaminated parts first, and then the rest.

It is assumed that all the billing will be carried out using hand tools (likewise as for the Active Central Laboratory, ACL).

It is also assumed that it will be too difficult to attempt to classify some of the waste as short-lived. Thus all waste that is radioactive is assumed to be deposited in the future store for long lived low and intermediate waste which SKB is planning to build.

3.2 Other documentation

A special (fourth) visit was paid to Studsvik in order look at the drawings of the building and especially to look for features of interest for how the various cleaning and dismantling steps actually are to be carried out.

The drawings are kept in a special archive and are in good order. The various features of interest could therefore soon be found.

One feature of special interest is the slit between the bottom of the concrete blocks containing the tubes and the bottom floor. The measurements given in the planning report [1] were confirmed. The slit thus has a width of 5 – 10 centimetres.

The material in the archive includes the procurement information. It is requested in the orders placed that the standards of the time be met. It can thus be expected that the concrete is properly reinforced with steel bars, and that it probably does not have a lot of voids.

The detailed design of the bottom part of the tubes was also confirmed / identified. Indeed, pieces of flat bars are welded across the ends of the pipes leaving most of the area uncovered. This is in full concordance with information received earlier in the investigation.

3.3 Plant visits

Four visits have been made to Studsvik. The SOILW was visited on two of these occasions and the Active Central Laboratory, ACL, on one occasion.

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12 It is pointed out in the report that this figuring is based on the ordinary density of concrete which is slightly below 2,5 metric tonnes per cubic meter. Actually, some of the concrete was made using crushed iron ore as a filler instead of ordinary sand. In this way the density becomes significantly higher and so also the shielding capability against radiation.

The plant visits very much confirmed and substantiated the information obtained from the reports. This is true for the actual observations made in the facilities as well as for the oral information given and the discussions held.

The plant visits did, however, clarify the preliminary nature of the present planning and illuminated the difficulties to be expected when reliable cost calculations are to be accomplished, particularly at an early stage.

It was explained that one of the fundamental difficulties is associated with the fact that it is impossible from the very nature of the issue to know beforehand what problems might surface during the course of the work. For instance, it is generally good strategy in decommissioning to remove the sources of the highest radiation first. When this is done, it becomes possible to make reliable measurements of those parts which have more moderate dose rates, but which nonetheless require attention. Moreover, activity might be hidden in fractures or behind surfaces covers and reveal itself only at a late stage of the operations[13].

Such effects have been experienced in the still ongoing work on the decommissioning of ACL. Progress reports have been contributed to an OECD/NEA[14] group working on decommissioning and a comprehensive final report is in preparation. This is part of an exchange of information taking place between different implementers.

[13] Actually, in accordance with a principle of caution in radiation protection, such hidden activity should always be expected and assumed until otherwise has been proven.

[14] OECD/NEA stands for the Nuclear Energy Agency (NEA) at the Organisation for Economic Cooperation and Development (OECD)

4 GUIDANCE DOCUMENTS

4.1 Strategy

The overall purpose of decommissioning is actually the protection of man, the environment and natural resources. In Sweden, the basis for this is defined in a law called *"The Environmental code" (SFS 1998:808)*[15]. According to part one, chapter one, section one of this code, it *"shall be applied in such a way as to ensure that human health and environment are protected against damage and detriment, ... biological diversity is preserved, ... the use of land ... is such as to secure a long term good management ... and reuse and recycling ... raw materials and energy is encouraged"*.

This is further specified in the radiation protection law SSI FS 1988:220 which has the following corresponding wording (1§): "*The purpose of this Act is to protect people, animals and the environment against the harmful effects of radiation".*

Planning for the financing - including the establishment of reliable cost estimates – is a part of this strategy, and these issues were described in section 1.2.

Cost calculations can, however, not be performed as an isolated or incidental event. They must be part of an integrated strategy involving all aspects of the planning and strategy of the life cycle of a plant.

Consequently, decommissioning should actually start at the design phase of a plant and be part of the overall long-term planning and management. By including decommissioning aspects from the beginning, the actual cleaning and dismantling operations can be carried out very efficiently and with insignificant impact on health, environment and natural resources.

Conversely, if no provisions and preparations for decommissioning were made in the design and construction phase of a facility, it is imperative that planning is being commenced "*as soon as possible*" ([5] section 2.16). In such a case, the extent of efforts required might be rather fortuitous, depending on what design features were actually chosen. The same can be said about the possibility to assess the extent of efforts required.

Nonetheless, the increasing realisation of these prerequisites in the international nuclear communities has lead to the establishment of procedures and development of tools[16] to manage the situation. In this regard, the IAEA has compiled the vast international experience into a number of Safety Guides. They are discussed in the subsequent section.

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15 In Swedish: Miljöbalken

16 Tools will be discussed in Section 5

4.2 IAEA safety guides

The most relevant IAEA Safety Guides for decommissioning are [5-8]. Other IAEA documentation of interest can be found in Section 8. Significant and relevant statements in these guides with regard to cost estimation issues include the following[17].

- The operator shall establish and maintain decommissioning plans that are commensurate with the type and status of the facility. The plans shall be periodically reviewed and updated with respect to the developments taking place (e g in technology).
- The operation organisation should retain the necessary resources, expertise and knowledge for decommissioning.
- The operation organisation should keep (in safe archives) records and documentation relevant to the design, construction, operation and decommissioning process so that such information can be transferred to any supporting or successor operating organisation.
- In all phases of the decommissioning, the public and the environment shall be properly protected from both radiological and non-radiological hazards resulting from decommissioning activities. The operating organisation should prepare a detailed assessment of those hazards including an accident analysis where necessary.
- A decommissioning option should be selected, and the selection should be justified in the decommissioning plan.
- A large number of issues should be considered including the following
  - radiological criteria
  - processes used and configuration of the facility
  - information on operation history
  - radiological and non-radiological hazards
  - types, levels and amounts of radio nuclides present
  - releases or spills
  - the availability of appropriate techniques and technologies for decontamination and dismantling
  - timing prerequisites
  - costs estimations and calculations
- The operating organisation shall plan for adequate financial resources to ensure the decommissioning of the facility. Safety assessments should form an integral part of such a plan.
- Before the final shutdown of a facility, the operating organisation should initiate detailed studies and finalise proposals for the decommissioning. The final decommissioning plan should include the following:
  - description of the facility
  - life history of the facility including significant modifications

[17] The extracted material presented in the present report should in no way be regarded as a substitute for the guides. Instead, studies of the entire Guides are highly recommended.

- an assessment of the amount, type and location of residual radioactive and hazardous non-radioactive material in the facility
- a description of the proposed decommissioning activities together with a schedule
- the rationale for selecting various options
- safety assessment and environmental impact statements (EIS)
- strategy for waste management
- worker's health protection programme including radiation protection
- quality assurance programme
- financial management including feedback of experience
- organisational and administrative controls

• The safety assessment for decommissioning should include radiological as well as non-radiological hazards. The assessment should form the basis for the protective measures to be applied.

• The degree and extent of contamination should be clearly determined early in the stage for decommissioning. Surveys should be conducted to determine the inventories and locations of radioactive, fissile and other hazardous materials.

• The cost of decommissioning should reflect all activities described in the decommissioning plan, including e g development of specific technology

• The so-called "*critical decommissioning tasks*" include "*characterization of the facility*" as a first step
  - A survey of the radiological and non-radiological hazards which is used as an input for the safety assessment for decommissioning and for implementing a safe approach during the work. The survey should be conducted to identify the inventory and location of radioactive materials and other hazardous materials. In planning and implementing surveys, use should be made of existing records and operating experience. A characterization report should be prepared which documents the information and data obtained during the characterization process.
  - An adequate number of radiation and contamination surveys should be conducted to determine the radionuclides, maximum average dose rates, and contamination levels for inner and outer surfaces throughout the facility. Contamination in shielded or self-shielded components, such as inside pipes and equipment, should be characterized. Special surveys should be undertaken to determine penetration depth and extent of contamination, when appropriate. The results of the surveys should be compiled into "maps" and other documents which will form a basis for the further planning.
  - An survey of all hazardous material in the facility should be conducted.

• The next step of the "*critical decommissioning tasks*" is "*removal of the residual process material*"

- Significant amounts of residual process material may be present in both planned and unplanned locations. Such material may give rise to hazards when disturbed during the decommissioning operations. It need therefore be removed at an early stage.
- Even after such removal, a significant amount of radioactive material may remain. The expeditious removal of such material should be considered.

• The next step of the "*critical decommissioning tasks*" is "*decontamination*". Before any decontamination technique is selected, an evaluation of its effectiveness and of the potential for reducing the total exposure should be performed. The evaluation should include consideration of probable radiation doses, cost-benefit analyses of radiological and waste management benefits, cost-efficiency studies, probability that available techniques will achieve the targets, and the amounts and types of wastes generated.

• The next step of the "*critical decommissioning tasks*" is "*dismantling*". There are many options available for dismantling, and their selection depends on types and characteristics of equipment and structures to be dismantled. Each dismantling task should be analysed to determine the most effective and safe method to perform it. The considerations include reliability and simplicity of dismantling equipment with regard to operation and maintenance.

• The last steps of the "*critical decommissioning tasks*" are "*demolition, surveillance and maintenance, and final radiological survey*". (Waste management is included under other headlines in the safety standards [5-8]).

5 INFORMATION FROM OTHER SOURCES

5.1 Introduction

There is a considerable literature on the topics of decontamination and decommissioning. Examples of literature surveyed are presented in section 8.

However, in order to stay within the scope of the present work, no general survey is provided. Instead, some issues of particular relevance to the SOILW and the calculation of the associated decommissioning costs are illuminated and also some examples are given.

5.2 Cost calculations for new facilities

There is relevant information to be compiled and used from the techniques of cost estimation for new facilities, and the following is taken from [9].

As soon as the final process-design stage is completed, it becomes possible to make accurate cost estimations because detailed equipment specifications and definite information are available. However, no design project should proceed to the final stage before costs are considered. In fact, cost estimates should be made throughout the various stages of planning, development and design in spite of the fact that complete specifications are not available.

Thus, cost estimates can be made even at the earlier stages and are then referred to as *predesign cost estimations*. If the design engineer is well acquainted with the various estimation methods and their accuracy, it is possible to make remarkably close cost estimations even before any detailed specifications are given. Such cost estimates frequently form the basis for the management in their decision on investments.

Five categories of cost estimates have been identified to be applied to the successive stages in a large chemical plant project [9]. These are as follows:

1 Order of magnitude (ratio estimate) based on similar previous cost data; probable accuracy of estimate over +/- 30 percent.

2 Study estimate (factored estimate) based on knowledge of major items of equipment; probable accuracy of estimate up to +/- 30 percent.

3 Preliminary estimate (budget authorization estimate; scope estimate) based on sufficient data to permit the estimate to be budgeted; probable accuracy of estimate within +/- 20 percent.

4 Definitive estimate (project control estimate) based on almost complete data but before completion of drawings and specifications; probable accuracy of estimate within +/- 10 percent.

5 Detailed estimate (contractor's estimate) based on complete engineering drawings, specifications, and site surveys; probable accuracy of estimates within +/- 5 percent.

Predesign estimates are based mostly on historical data from similar facilities together with utilisation of adjustment factors for cost increase with time, size of the facility and/or composition of the intended equipment. Late estimates are instead largely based on detailed specifications and summations of all the items which contribute to the total cost.

It is important to realise the uncertainties associated with the various stages and possibilities for estimation. Some of them are arbitrary in character as the ones given in the listing above. Others are systematic in character and thereby perhaps more treacherous.

Pitfalls in this context include the following:

- *Conceptual error.* Performing the "correct" calculation for the wrong process, or for an incomplete one.
- *Methodological error.* Applying the summation method at too early a stage when only a fraction of all items to be included can be identified.

In the vast majority of cases such systematic errors lead to underestimation of the actual cost.

5.3 Cost calculations for decommissioning

Many sources deal with cost calculations specific to decommissioning, e g [10-16].

It is pointed out e g in [13] that the method selected for the decommissioning is the most significant factor for the cost. The selection of methodology is, in turn, strongly dependent on the radiological condition. This is an area that is generally not addressed in great enough detail. According to [13], variances of +/- 100 % for the influence on cost may be experienced in the case of prognoses for a nuclear power plant. There is no reason to believe that the uncertainty would be any less for SOILW unless a radiological survey is carried out.

Chapter 12 in [14] is the paper among those mentioned above which provides the clearest perspective on successive estimates and calculations. The account given is actually quite similar to the one in [9] dealt with in section 5.2. According to Chapter 12 in [14], the following stages can be identified:

1. *Order-of-magnitude estimate.* Such an estimate can be determined without detailed engineering data using scale-up or scale-down factors and approximate ratios. The expected level of accuracy is -30 % to + 50 %.
2. *Budgetary estimate.* A budgetary estimate can be made based on a general idea on what methods and equipment to be used (and this presupposes results of some radiological surveying). Detailed

engineering data are not needed at this stage. The expected level of accuracy is -15 % to + 30 %.

3 *Definitive estimate.* The details of the project have been prepared including engineering data. The expected level of accuracy is -5 % to + 15 %.

Different techniques for estimation apply at different stages, and the following ones are described in Chapter 12 in [14]:

- Bottoms-up technique
- Specific analogue technique
- Parametric technique
- Cost review and update technique
- Expert opinion technique

It is obvious from what is just said that the uncertainty of a cost calculation can vary very strongly depending on what background material is available in terms of amongst other items radiological surveying, technology selection and stage of technical planning. It is therefore important that the state of development and the type of methodology are clearly stated as well as the estimated uncertainty.

5.4 Methodology and alternative selection

It was pointed out already in the previous section that the most important factor for the cost calculation is the selection of technology to be applied. This selection depends in turn on the radiological condition and on the design of the plant. The selection also depends on the methods and technologies which are available.

It might be tempting at this point to conclude that the choice should be a straightforward one based on the prerequisites at the facility and the specifics of the different methods. This is frequently not the case. In many cases, a balance has to be found, e g on efficiency against generation of air-born activity or secondary waste [14,17-18]. Also, the various choices of methods may be interdependent.

Another aspect is that the scale of the need should be identified at a sufficiently early stage. For instance, if the initially identified need for billing is small, hand-held tools might be chosen. If the actual need is much larger, and this is identified only gradually, the appropriate selection of remotely controlled billing might not take place.

Alternatively, since most of the radioactivity usually remains within 5 millimetres from the surface, a laser based decontamination technique might be considered, [19].

Another example may be that of drilling and mechanical fracturing. In the cost calculations for SOILW [1] it is assumed that the fracturing be carried out by making an array of drill holes and subsequently fracturing the concrete by using special inserts in the holes which cause fracturing by mechanical action.

It is not known to the present authors if tools are actually commercially available for the thickness of blocks in question. Instead, expanding cement (Swedish: "snigeldynamit") might be applied to cause the fracturing. However, even so, it is likely that the pieces of concrete still stay together through the steel bar reinforcements. Consequently, it might be appropriate to consider other techniques for dividing up the concrete into blocks of manageable sizes. One such technique is chain sawing. However, such a technique might generate secondary waste and cause airborne contamination.

The implication of this example is that it is frequently necessary for the implementers to study different alternatives, and to make a selection of technique according to some suitable methodology. Several safety / system analysis tools are suitable for the identification of the different possibilities [20-21]. There are also tools available [22-24] for selection and decision making.

In short, for an alternative to be selected, it should be assessed to be preferable compared to other alternatives according to some predetermined evaluation procedure. Sometimes, such a procedure might actually be quite simple. For instance, it might comprise a short list of the most important aspects together with a range of grades to be given for each of the aspects.

5.5 A similar example

A project similar to the one of SOILW at Studsvik has been carried out at the Argonne National Laboratory in Illinois. The facility in question is referred to as the East Map Tube Facility.

The following is an extract from the original article [25].

The tube map facility consists of a monolithic concrete structure 13 feet wide, 28 feet long and 21 feet deep (19 of which is below grade). A series of 129 storage pipes of various diameters were cast vertically into the concrete structure. The pipes, 6, 8 and 10 inches in diameter, were cast-iron, bell and spigot sewer pipes containing two joints sealed with lead, one near the top and one at the bottom.

The pipes were used to store small, highly radioactive objects placed in metal containers. The containers were similar to tubes used to store maps and drawings, hence, the name Map Tube Facility.

Objects stored in the facility included nuclear reactor components and assemblies, materials samples, and irradiated metal objects. The objects were stored until disposed or used in research experiments.

During its active life, a removable roof covered the facility. The roof deteriorated and was removed from the structure in the late 1970s. Removal of the roof allowed precipitation to enter the pipes through deteriorated upper pipe joints and leakage around loose fitting lead pipe caps. The presence of water in the pipes accelerated corrosion of the objects and spreading contamination within the pipes. Corrosion of the pipes and objects resulted in the generation of several inches of sediment in each pipe.

Deterioration of the lead filled joints and cracks in the surrounding concrete is thought to have permitted radioactive water to migrate out of the facility, contaminating underlying groundwater with low levels of tritium, cesium-137, and strontium-90.

In the fall of 1993 the facility was characterized in preparation for the decontamination operation. All 129 pipes were opened and surface radiation levels measured. The most highly radioactive pipes were inspected with an underwater camera to determine the source of radioactivity. Highly radioactive objects were discovered in six of the pipes. Several pipes with high radiation levels were empty of objects. Underwater radiation dose rates near objects were measured and smear samples and samples of water and sediment were collected and analyzed.

The information thus obtained was used for the planning of the operation. It took place as follows.

The pipe interiors were scrubbed with a stiff brush to remove loose contamination. The interior of the pipes were then washed with a high pressure water spray. Once the pipes were cleaned, they were re-examined. Some pipes that were initially thought to be empty were found to contain small objects such as bolts, clamps and wires. These objects were removed with long reach manipulators and packaged with the sediment.

The removal of the water, sediment and objects greatly reduced the amount of contamination present in the pipes and permitted more accurate assessment of the degree of residual contamination within the pipes.

When the decontamination process was complete, the dismantlement operation began. A schedule was established which permitted the most highly contaminated pipes to be removed first.

Each of the pipes was fitted with an internal lifting device consisting of a steel bar attached to a cable.

A concrete coring rig was used to cut each pipe from the concrete matrix. Each pipe was cut from the structure in one continuous 21 foot long coring operation through solid concrete. The loose core was then lifted from the concrete matrix.

Since the two pipe joints extended approximately two inches beyond the outside diameter of the pipe, it was necessary to use some custom-made core tool larger than the outer diameter of the pipe. This resulted in the removal of the entire pipe and several inches of surrounding concrete. To reduce waste quantities, the core diameter was selected to minimize the amount of concrete removed along with the pipe. Careful control of the coring operation was required to prevent the core tool from cutting into the pipe or joint.

The coring operation was generally very successful, however, significant problems were encountered early in the process. The first attempts resulted in the coring bit cutting open the pipe near the base of the structure, releasing radioactive material and finely divided lead particles into the cooling water loop. Further investigation determined that the pipes were not exactly vertical, but were off-plumb by as much as four inches. Attempts to angle the coring operation to coincide with the angle of the pipe were unsuccessful. Coring at an angle appeared to accentuate the normal drifting of the tool, making accurate cuts impossible. It was finally determined that the most effective approach was to drill vertically, off setting the rig at the surface to compensate for the off-plumb nature of the pipes.

The original coring rig was too light to withstand the stress of such a deep coring operation and was unable to maintain the orientation of the core. To improve control of the coring operation, a larger coring rig was brought in.

The diamond tipped coring bit operated under a constant flow of drilling water to cool the bit and carry away the fines. On several occasions, the coring tool encountered voids within the concrete and objects such as pipes and other metal objects not shown on the construction drawings. Encountering these obstacles resulted in loss of cooling water flow which damaged the cutting tool. Approximately 10 of the 129 cores had to be temporarily abandoned and grout injected in the core hole to fill the voids. Once the grout hardened the pipes were cored.

The project was successfully completed in late October 1994, within budget, ahead of schedule and with minimal worker exposure. All 129 pipes were removed and shipped to Hanford. The concrete monolith, with pipes removed, will remain in place until the surrounding soil and groundwater can be fully characterised and cleaned up.

6 DISCUSSION AND CONCLUSIONS

The Swedish system for financing requires that the implementers make estimates and calculations for costs for decommissioning and dismantling of nuclear facilities. Special provisions are made for the studied facility at the Studsvik site which formerly was the centre for development of nuclear power in Sweden.

The cost calculations should be recurrent and utilise the knowledge available at each stage. This implies that estimates are made in the early stages based largely on experience and comparison. In the later stages, calculations can be made based on comprehensive and detailed plans.

Each cost estimate or calculation should clearly state the following:

- Rationale for selection of methodology with respect to stage of planning. The selection should be based on reasonably conceivable options.
- The estimated error, type of error (random or systematic) as well as basis for the estimate / calculation.
- List of items which may be uncertain, the grounds for the uncertainty and – if feasible – what might be done to reduce this uncertainty.
- Timing considerations. The rationale / implications of the timing chosen, alternatively what might be the consequences of different decisions on the timing.

It should be noted in this context that the recurrent cost calculations together with their respective uncertainties have significance beyond that of the planning and the decommissioning itself. It also supports the confidence building among the parties involved, including those representing the public.

The precision of a cost calculation depends heavily on the quality and stage of development of the basis for the calculations. Important prerequisites in this regard include the following documentation:

- Descriptions of the facility in question and its schemes of operation
- Radiological maps and descriptions
- Descriptions on alternative schemes for decontamination and dismantling including alternative methods. This relates primarily to methods which are commercially available and for which the expected performance is known. However, suitable methods might not be available commercially. In such cases, the potential of development work should be considered.

An integrated planning, including the various aspects of decommissioning is essential for the recurrent cost calculations. This includes the above mentioned plant descriptions, radiological surveying, and decontamination and dismantling technology.

The selection of methodology should be carried out in some systematic way e g by using systematic analytic process tools or tools used in system analysis.

In order to develop firm calculations for the future decommissioning costs of the SOILW we propose that the process starts with a general radiological mapping of the facility. In the next step of the renewed calculations of the decommissioning costs this mapping can be used as a basis for the further planning. One crucial point will be to select a technical route which will provide the basic assumptions for improved calculations. After this step has been finalised, an appropriate estimate of the decommissioning cost should be achieved at a confidence level of at least 80 %.

In this study we have illustrated that the task of finding appropriate cost estimates may have to start with radiological mapping at the site / facility. In this way, sufficient information may be accumulated in order for an appropriate technical planning to be carried out, including choice of methodology to be utilised.

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8 SURVEYED LITERATURE

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