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COST CALCULATIONS AT EARLY STAGES OF NUCLEAR RESEARCH FACILITIES IN THE NORDIC COUNTRIES

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ABSTRACT

The Nordic countries Denmark, Norway and Sweden, and to some extent also Finland, had very large nuclear research and development programs for a few decades starting in the nineteen fifties. Today, only some of the facilities are in use. Some have been decommissioned and dismantled while others are at various stages of planning for shutdown. The perspective ranges from imminent to several decades.

It eventually became realized that considerable planning for the future decommissioning is warranted and that an integral part of this planning is financial, including how financial funds should be acquired, used and allocated over time. This necessitates that accurate and reliable cost estimates be obtained at all stages. However, this is associated with fundamental difficulties and treacherous complexities, especially for the early ones.

Eventually, Denmark and Norway decided not to build any nuclear power plants while Finland and Sweden did. This is reflected in the financing where the latter countries have established systems with special funds in which money is being collected now to cover the future costs for the decommissioning of the research facilities.

Nonetheless, the needs for planning for the decommissioning of nuclear research facilities are very similar. However, they differ considerably from those of nuclear power reactors, especially with regard to cost calculations. It has become apparent in the course of work that summation types of cost estimation methodologies give rise to large systematic errors if applied at early stages, in which case comparison based assessments are less biased and may be more reliable. Therefore, in order to achieve the required quality of the cost calculations, it is necessary that data and experience from authentic cases be utilized in models for cost calculations. It

also implies that this calculation process should include a well adopted learning process.

Thus, a Nordic co-operation has been established for the exchange and evaluation of cost-related information on nuclear research facilities. The aim is to identify good practices, accumulate experience, compile data from actual plants and projects, and to derive methodology for cost calculations, especially for early stages.

The work includes the following tasks which constitutes the bulk of the present paper:

- identification of good practice with regard to the following:
 - strategy and planning
 - methodology selection
 - radiological surveying
 - uncertainty analysis
- descriptions of relevant plants, features and projects
 - decommissioning of reactor DR 1 in Denmark
 - decommissioning of reactor R 1 in Sweden
 - decommissioning of the pilot scale uranium fuel reprocessing plant in Norway
 - planning for the future decommissioning of the TRIGA reactor in Finland
- techniques for assessments of costs introduction

Early developments

The Nordic countries, Denmark, Finland, Norway and Sweden, were very early as well as ambitious in developing nuclear technology. Iceland has very large hydropower and geothermal resources had consequently less incentive to join the race. Finland had a special relation with the Former Soviet Union after the Second World War which impeded the actions to a certain extent.

After the Second World War, Norway was in a unique position in that it possessed heavy water that made it possible to

build atomic piles using natural uranium. This heavy water originated from the Norsk Hydro A/S water electrolysis plant at Rjukan where it could be beneficiated as a result of the isotope effect in the process.

Thus, the first nuclear reactor in the Nordic countries, JEEP 1, was commissioned at Kjeller outside Oslo in Norway already in 1951, preceded only by facilities in Canada and in the four great powers United States, The Soviet Union, Great Britain and France. It was clearly stated that “*the project should be open and without any secrecy arrangements*” and that the *Institute for Atomic Energy*, IFA, should aim at establishing co-operation with other countries having similar approaches, e.g. Sweden and France. (In 1980, IFA, changed its name to *Institute for Energy Technology*, IFE.)

At the time of the commissioning of the JEEP 1 reactor (in Norway) in 1951, the great powers had control over most of the uranium available. Nonetheless, IFE managed to purchase uranium from the Netherlands. This contract also included co-operation, which continued in various forms for a long time.

The Nordic countries became active participants when new international organizations were planned in the nineteen fifties and it was in Norway that the first international nuclear conference was organized already in 1953. This was two years before the conference on the Peaceful Uses of Atomic Energy (The Geneva conferences) held by the United Nations.

The first Swedish nuclear research reactor, R 1, was located at the Royal Institute of Technology in Stockholm and was commissioned in 1954. The moderator consisted of heavy water which was supplied from Norway.

The three tones of natural uranium needed for the fuel at the start of the R1 reactor in Sweden was “borrowed” from France. However, Sweden soon became independent of foreign suppliers since mining at Kvarntorp (and later Ranstad) and subsequent beneficiation generated natural uranium at a capacity of five tones per year already in 1953. Denmark and Norway also had extensive programmes for uranium mining and beneficiation (Greenland and Einerkilen, respectively)

Denmark acquired two reactors from the United States in 1956, and a larger one from Great Britain in 1957. They all used enriched uranium in the fuel. The small training reactor (DR 1) used uranium dissolved in a liquid homogeneous liquid reactor, and this concept was subsequently studied in Denmark for power generation purposes.

Finland started its nuclear technology in 1956 by a subcritical pile, which used natural uranium as fuel and light water as moderator. The next step was the purchase of a TRIGA reactor from USA and to balance the political situation small amount of enriched fuel for the subcritical pile was bought from the Soviet Union in order to increase its reactivity. In both purchases there was a third party, IAEA, in the agreements. The TRIGA reactor uses enriched uranium fuel. It went critical in 1962 and is still in operation.

The programs in Denmark, Norway and Sweden included full and complete fuel cycle activities with mining, beneficiation, reprocessing and fuel manufacturing. Much of the work was carried out in co-operation between the countries.

Thus, a pilot scale spent fuel reprocessing facility (Uranrensanlegget) was in operation in Norway during 1961-68, and during this period 1 200 kg of irradiated fuel was reprocessed in various joint efforts between Holland, Norway and Sweden.

Similarly, the so-called Active Central Laboratory (ACL) was built at Studsvik, Sweden, during 1959 to 1963. It was intended for the dual purpose of laboratory scale research around reprocessing and fuel development, and pilot scale mixed oxide fuel fabrication. However, no equipment was ever installed for the latter purpose.

Early work also included the Ågesta nuclear power plant in the outskirts of Stockholm in Sweden. It was commissioned in 1962 and taken out of operation in 1974. Initially, it used heavy water as a moderator and fuel containing natural uranium. The latter was subsequently changed to fuel with some enrichment in order to increase the power output. The reactor had a thermal power of initially 65 and later 80 MW. It generated electricity as well as district heating.

Eventually, Denmark and Norway decided against nuclear power, while Finland and Sweden went ahead with programs for light water reactors and enriched fuel. The national and Nordic co-operative programs have left behind a large number of nuclear research facilities in various stages of decommissioning.

Much of the reference material on the initial development of nuclear technology in the Nordic countries is written in the local languages[1-2], see also [3]. Summaries and similar articles in English are can be found in [3-4].

Present situation

Some facilities have been decommissioned such as reactors in of Denmark, Norway and Sweden, one reprocessing pilot plant in Kjeller in Norway and the Active Central Laboratory at Studsvik near Stockholm in Sweden. Others have been taken out of operation and await decommissioning, such as the research reactors R2/R2-0 in Studsvik, Sweden. Some facilities are still used today, e.g. the Halden (heavy water) Boiling Water Reactor (HWBR) in Halden in Norway and the TRIGA reactor in Helsinki in Finland.

Work is presently in progress in Denmark on decommissioning of all of their nuclear facilities at Risø near Roskilde to green field conditions within a period of up to 20 years. Approval for funding was made in a Parliament decision in 2003 after which the organization Danish Decommissioning was formed.

In Norway, present work includes comprehensive planning for upcoming and future decommissioning activities.

In Finland and Sweden, planning for decommissioning is made under the rules for radiation protection and nuclear safety as well as the requirements of the systems for funding. The purpose of the latter are to ensure that adequate funds to cover all future costs are accumulated today when the benefits of the nuclear power are reaped. The system ensures that the burdens for decommissioning will not be passed over to future generations. This means that an estimate of all future costs has to be submitted to the pertinent Authority / Government Agency for reviews and decisions. The reviews are made based on the expertise of the officials as well as on the knowledge base compiled by various consultants.

It was soon found in such work [5-6] that the financial planning is intimately related to and mutually dependent on the decommissioning planning in general. In fact, the timing of various planning activities for decommissioning is largely dictated by the requirements on the cost calculations. It was also found that financial planning and cost estimations are

necessary for the decommissioning planning in general since the former are needed for e.g. selection of techniques to be applied.

It might be tempting to assume that methodology developed for planning and cost calculations for nuclear power plants can be directly applied and reproduced without any modification to old research facilities. It was found [6], however, that the existence of a nuclear power program is of limited value for old research facilities since there are substantial differences. Actually, an uncritical application of power plant approaches is likely to lead to major and systematic underestimations of the undertakings as well as the costs for several reasons:

- lack of records in combination with limited or no access to staff who designed and operated the facilities
- much less is known about an old research facility and thus the list of items to be summed over is incomplete
- the dependence on volume is different since the volumes are small
- the spread in design and operation features is much greater
- design features that are less suitable for decommissioning

Instead, it was found that there are substantial common interests between owners of different research facilities in different stages of decommissioning:

- comparisons can be made with similar and finished projects so that compensation is made for summations over incomplete sets of items
- feedback of experience can be gained from completed projects on similar facilities
- resources can be saved by joint efforts

Once these benefits of joint Nordic work had been identified [3,5-6], the *Swedish Nuclear Power Inspectorate* took initiative to a Nordic co-operative project. It was started in 2005 and is presently (2007) in progress. The purpose of the work is to start an active learning process in order to define good practice, to identify and develop cost estimation methodology and to compile a common knowledge base. The latter includes e.g. making old documentation available and searchable using modern digital techniques. The results of the work during 2005-06 have been documented in [3].

The participants of the Nordic co-operative project are as follows:

- *Danish Decommissioning (DD)*
- *Institute for Energy Technology (IFE)*
- *Studsvik Nuclear AB (Studsvik)*
- *Technical Research Centre of Finland (VTT)*
- *The Swedish Nuclear Power Inspectorate (SKI)*
- *The Swedish Radiation Protection Authority (SSI)*
- *Tekedo AB (Tekedo) (co-ordinator and consultant)*

The work is financed by the participants (except Tekedo) together with *The Nordic Nuclear Safety Research (NKS)*. Actually, the SKI has provided a large share of the financial as well as in kind support to the project.

NKS is a scientific co-operation program in nuclear safety, including emergency preparedness and radiation protection, serving as an umbrella for Nordic initiatives and interests. The objective is to carry out joint activities and to publish the results and findings in the open literature, e.g. in the NKS series (see www.nks.org). Such reference material offers guidance to ministries, authorities, research establishments, facility owners and suppliers in the nuclear field.

PURPOSE AND SCOPE

Purpose

The purpose of the present work is as follows:

- to identify what knowledge and methodology is required for *sufficiently precise** cost calculations for decommissioning of nuclear research facilities
- to exchange, arrange and compile such information, data and methodology so that they become available in a suitable format
- to establish a Nordic network for information exchange and co-operation

* "*Sufficiently precise*" is tentatively defined such that the incurred cost should fall within $\pm 20\%$ of the estimated one with a probability of 65 %.

It has been assessed [5-6] that a confidence level of 80 % might be attained even at a relatively early stage. Furthermore, it has been pointed out by organizations such as the *Association for the Advancement of Cost Engineering International (AACE)* that a cost estimate has little meaning unless there is some quantification of the uncertainty. [7]

Scope

The scope of the Nordic co-operative work is as follows:

- 1 to establish of a Nordic network in the area of decommissioning of nuclear research facilities
- 2 to prepare a background for the prerequisites for precise cost calculations, including
 - a brief general description of types of nuclear technology development work carried out historically in the Nordic countries
 - a brief survey of existing nuclear research types of facilities
- 3 to prepare a guidance document for the prerequisites for precise cost calculations, including
 - good practice on radiological surveying including statistical prerequisites for sufficient data and interpretation
 - good practice on technical planning including methodology selection including logistics and timing aspects
 - financial risk identification, assessment and evaluation including approaches similar in nature to hazard identification and safety analysis type of approaches
- 4 to describe techniques that may be applied at early stages of calculations and assessments of costs
- 5 to present examples of projects at different stages of planning and completion, including experiences made and lessons learned:
 - the R1 research reactor in Sweden

- the reprocessing pilot plant in Norway
 - the DR 1 research reactor in Denmark
 - the TRIGA research reactor in Finland
- 6 to compile and make digitally available in a searchable format, e g on the internet, various documents of interest

GOOD PRACTICE

The rationale for descriptions of good practice

Recommendations for decommissioning work as well as specific advice on cost calculations have been issued by the IAEA [8-9] and the OECD/NEA [8]. They form the framework for all the work carried out in our project. These recommendations can be implemented in various ways, and indeed different approaches can be found in the literature.

However, from a systems analysis point of view, a decommissioning project can be rather complex with decisions having to be made from time to time based on incomplete information. Consequently, there is a need for compilations of what might need to be considered for planning and cost estimation purposes, and this is the rationale for the present description of good practice.

Radiological surveying

The cost for decommissioning is closely related to the presence, extent, character and distribution of remaining radioactivity. Frequently, the cost for decommissioning of a nuclear facility is a couple of order of magnitude higher than for a corresponding (hypothetical) non-radioactive plant.

Moreover, the costs for radiological measurements and experts may be a considerable fraction of the total cost, maybe even more than half of the total project. [10-11]

It is important that the basis for radiological surveying is conceptually appropriate. Firstly, it must be realized that radiological surveying is different for the operation, the planning and for the execution of the decommissioning. [12-13] In practice, this may mean that considerable amounts of sampling, measurements and analyses need be made at the time of planning and cost estimation, and maybe several decades before the actual decommissioning takes place. What really dictates the extent of work is what is required for appropriate selections of techniques to be used and for estimations of the costs involved.

This may imply that a radiological model should be established and validated [12-14, based on the design and operation of the facility as well as actual radiological measurements. Such a model will facilitate the analysis underlying the plan for the radiological surveying leading to the achievement of an accuracy in the cost estimates of $\pm 20\%$. This is usually an iterative process in which subsequent steps are based on the outcomes and associated conceptual and statistical analyses of the previous ones. It is important that the likely influence of lack of data as well as of all errors that may be associated with the collection of data be appropriately evaluated with regard to level and uncertainty of the estimated cost.

The radiological surveying should be tailored with respect to the features of the plant in question. Generally, it must be realized that much of what can be assumed for nuclear power plants might not be directly applicable to research facilities.

For instance, in light water reactors with little fuel damage, the general contamination comprises activation products from outside the fuel (but including the outer surfaces of the fuel pins). Usually, cobalt-60 is the dominating radionuclide. It has a half life of around five years and the energy of the gamma rays emitted is high so that the radiation is quite penetrating. Frequently, the alpha to gamma and beta to gamma ratios to be used for the regular radiation protection work can be determined generically from a concentrate of primary system reactor water. It can usually be shown that the alpha and beta emitters constitute a small health hazard compared to that of cobalt-60.

In a research facility, none of this may apply. The hazard may actually be dominated by radiation that is prone to shielding and therefore may hide in fissures and fractures. Errors may occur even in the presence of gamma emitters, e g if the contamination inside a pipe is to be estimated and the shielding effect is not estimated based on the actual radionuclide spectrum (the actual radiation being weaker than e g that of cobalt-60). Radionuclide composition may even vary from room to room depending on the various historical uses.

Insufficient knowledge of the presence of radioactive substances might lead to unexpected problems (and associated costs) during decommissioning. Unforeseen radioactivity may constitute a hazard that warrants more protective equipment, time consuming methods or expensive tools. This includes activity that might not have been possible to measure due to various geometric constraints (e g bulky components). Even a very low level of unforeseen contamination may give rise to large volumes of radioactive waste that may have to be stored for a long time awaiting disposal in expensive facilities. The mere time delay and rescheduling for additional surveying may also have a large impact on the total costs, since every project is connected with base costs that might not disappear when decommissioning is halted. Moreover, if contamination is found in unexpected places, the program for final survey may have to be considerably extended.

Technical planning and methodology selection

The cost for decommissioning is closely related to the strategies and methods used. There are usually different alternatives available and the best or optimal choice should be based on the plant prerequisites in combination with the features of each method. Both of these may be associated with incomplete knowledge and uncertainties which then transfer to the cost calculations. A rational selection between alternatives cannot actually be made until costs can be compared.

There are many reasons why the knowledge needed may be incomplete.

Plant prerequisites include design and operation history as well as data from radiological surveying. It is important that the full intensity and extent of the activation and contamination be realized, or else the methodology may have to be changed when such features become apparent. Uncertainty in this regard that cannot readily be resolved beforehand should call for preparedness to shift methodology whenever warranted based on upcoming information.

There are many vendors around who offer more or less sophisticated technologies. It is sometimes thought that decommissioning of a nuclear facility requires the availability and use of novel techniques that have to be developed in conjunction with a project. However, the general experience is

that the technologies used need not be nearly as sophisticated as those used for the construction of the plant.[15]

Nonetheless, it might be cumbersome to find information on the relative merits of various methods, and on how the use of one method or another will influence other work and stages in the project. Such information may not be obtained in an unambiguous form from various vendors.

It may be observed that successful projects are associated with compiling and sharing experience with other facilities and projects. This includes how to best use standard hardware store type of equipment in which case little financial reward may be achievable for a vendor. In other cases the information sharing may include sophisticated methods, e g robots and remotely controlled equipment.

Financial risk identification and evaluation

Experience shows that cost drivers more often than not have a profound influence on costs. They typically come as surprises during the course of the execution of a decommissioning task and thereby give rise to overruns.

It is thus imperative that cost drivers be identified, preferably during the planning stages, but if this is not possible, as early as possible. In practice, the cost drivers can be identified in different ways, to varying degrees and at different times. It is helpful in this regard to attempt deterministic as well as probabilistic types of analyses.

The simplest way in which to achieve this is through a special task of risk and uncertainty identification. Different sources should be consulted in order for the compilation to be as complete as possible. It is highly desirable that individuals with different kinds of competence and experience are involved in this work. A few examples of what might be attempted are given in the following:

- a systematic analysis of the various aspects of the facility
- brainstorming
- follow standard check lists
- review literature
- utilize feed-back from previous projects
- networking internationally
- active learning techniques

The assessment of the various types of uncertainties identified relates to the following questions:

- Where might there be deviations?
- How likely is it?
- What would be the consequences (including worst case)?

In some cases, such a risk identification type of approach might not be sufficient in order to achieve the desired $\pm 20\%$ uncertainty, e g due to difficult access or personnel dose problems. Consequently, this may call for an extended uncertainty analysis which would include a systems definition (including the borders to other systems) together with descriptions of features, events and processes. This enables risk identification and evaluation as described above to be carried out in a systematic and detailed manner. Such analyses should be recurrent which pinpoints at the need for comprehensive and proper documentation.

TECHNIQUES FOR COST CALCULATIONS

The main purpose of cost estimation is to obtain bases for decisions. One obvious such decision concerns the general allocation of adequate funds to cover an entire decommissioning project. But decisions are also needed at different times and for other purposes as well. For instance, cost calculations are required in order to make rational and appropriate choices of technology.

Estimations of costs at different stages and for different purposes have been carried out for decades in e g the chemical process industry. Textbooks on the subject, e g [16], explain that there are two principally different types of methodology for cost estimates:

- Comparison with incurred costs for processes and other parts of facilities already erected, using various types of comparison factors, including scale factors
- Summation based on known volumes of various items together with known costs per unit.

In the following these will be referred to as comparison and detailed summation methods, respectively.

At early stages, the detailed summation method would give rise to large systematic errors since only a fraction of the terms to be summarized may be identified. Consequently, the comparison method is recommended for such situations, and in the first stage it can be expected to deliver a precision of $+50/-30\%$. Similarly, at the last stage of cost calculations, when the final detailed design has been completed and binding quotations have been received from all of the suppliers and contractors, the detailed summation method can be applied with a typical precision of $\pm 5\%$. The former alternative is normally not good enough to use as basis for decisions, whilst the latter level of precision meets the target.

It should be noted in this regard that cost calculations for nuclear research facilities are particularly treacherous and uncertain for several reasons including the following:

- Plans for decommissioning do not exist
- The facilities were not designed for decommissioning
- The facilities are small (which means that investigations can become expensive in relation to the total cost)
- The facilities are very different in character
- The types of contamination are different
- The buildings were constructed and operated at a time when the regulations were considerably less strict than today
- Incomplete documentation of the operation history, accidents and incidents causing contamination
- Institutional memory has been lost and people who are able to recall what took place may not be around any more

The need for decisions at early stages in combination with the need for accurate cost calculations as a basis for such decisions raises the requirement that the cost calculations need be accurate already in the early stages.

Such requirements for accuracy clearly exceed the $+50/-30\%$ indicated above for first stage calculations. Thus,

methodologies need to be developed for more precise calculations already at early stages.

Increased precision for early stage calculations might be achieved if one or both of the following might be achieved:

- 1 Improved precision with the comparison method by using incurred costs of similar facilities
- 2 Improved precision with the summation method by finding out more about the detailed features for certain parts of a decommissioning project

Both methods rely on data from incurred costs for various completed projects. The implementation of method 1 above implies that similar facilities exist and that parts of facilities lend themselves to comparison. In method 2, factors are introduced that express the complexities and difficulties of different tasks.

EXAMPLES OF NORDIC PROJECTS

Introduction

Four plants have been studied in some depth in addition to the general compilation of facility and decommissioning data in the project. They represent different types and generations of facilities, as well a different times and stages of decommissioning. As a result of these differences they also represent somewhat different approaches to decommissioning.

Only some key issues are highlighted here. For full information the reader is referred to [3].

The R1 research reactor in Sweden

The R1 research reactor was moderated by heavy water and used natural uranium fuel. It started operations in 1954, was closed in 1970, and decommissioning was completed in 1981. The reactor was located in crystalline rock at the Royal Institute of Technology in Stockholm, Sweden, see Figure 1. The decommissioning was carried out by Studsvik.

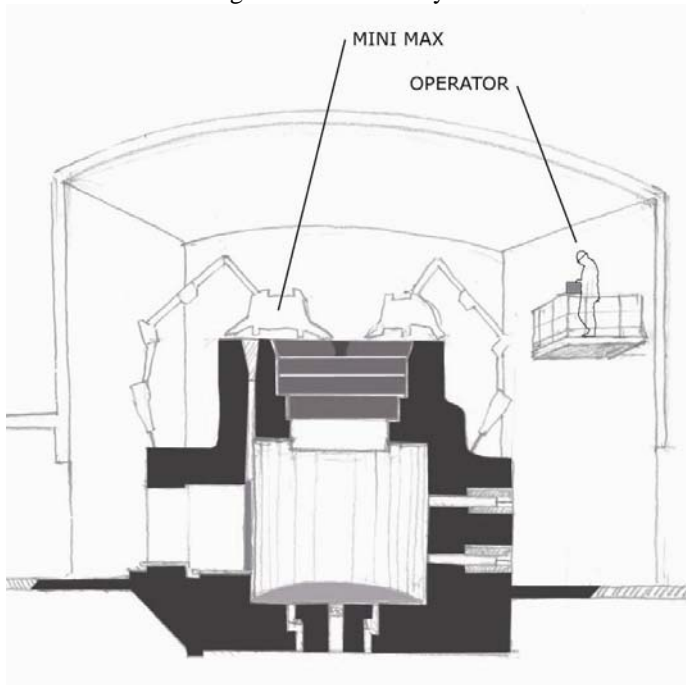


Figure 1. The R1 research reactor in Sweden.

Some features and findings are as follows:

- The decommissioning was carried out while there was still ample access to people who had worked in the facility.
- Extensive information searches and plant visits were made in the planning stage.
- The sampling of the graphite reflector was limited at the planning and cost estimating stage since it gave rise to dose to personnel. It turned out once the reactor tank had been lifted that the dose rate was considerably higher than assessed. This meant a cost increase for this part of the project.
- A timber handling machine was modified with a pneumatic hammer and remote controls. This made the work much more efficient and saved dose, and helped in reaching all the targets for the project.¹

The reprocessing pilot plant in Norway

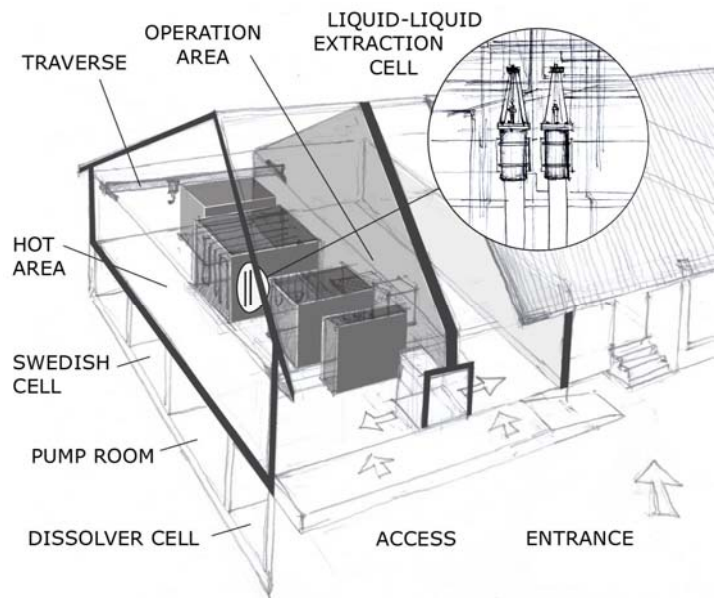


Figure 2. The reprocessing pilot plant in Norway.

The uranium fuel reprocessing plant was commissioned in 1961 and taken out of operation in 1968. It was decommissioned partially in 1982 and fully in the period 1989 – 1993. The work comprised more than 6 000 meters of piping and a total of 50 tanks, evaporators and extraction columns. It was located at the IFE facilities in Kjeller at the outskirts of Oslo, and it was IFE who carried out the decommissioning project. A drawing of the facility is presented in Figure 2.

Some features and findings are as follows:

- The project was carried out while there was still institutional memory left from the time of operation. This was fortunate since one of the lessons learned was that it is important to conserve all essential written information and drawings.
- The project itself was very well documented, partly within the NKS co-operative framework. E g, valuable advice is

¹ Actually, this was the origin of the present product line of the Swedish Brokk company.

given on how to best handle various partially modified standard tools for the various demanding tasks in decommissioning work.

- It is pointed out that “*Dismantling work, by its proper nature, will often be seen by the crew as a demoralizing, destructive task. The physical work is mostly tough, complicated and time consuming. Such a job will generally require twice the working hours compared with more conventional tasks*”. Several points of specific advice are given as to how management can reverse any such effects.

The DR1 research reactor in Denmark

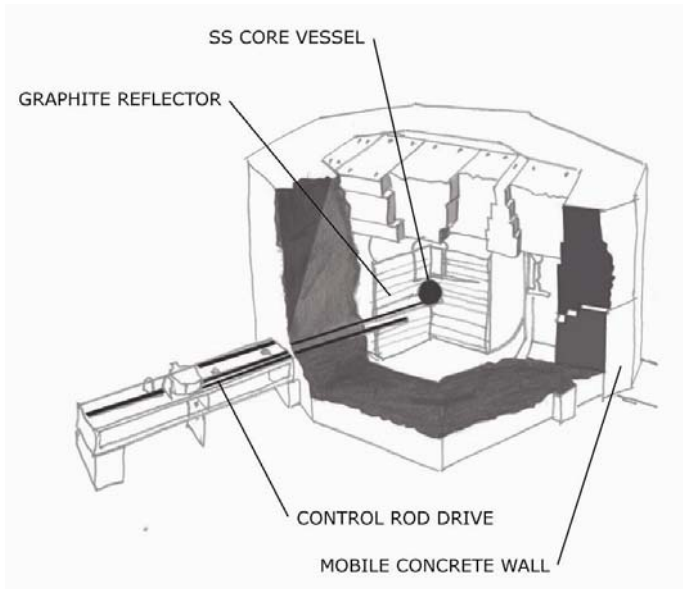


Figure 3. The DR1 research reactor in Denmark. It had liquid fuel in the core vessel.

The DR1 reactor at what is now called Risø National Laboratory, Technical University of Denmark – DTU was commissioned in 1956, taken out of service in 1975 and decommissioned in 2004-05. It was supplied by Atomics International in the USA and was decommissioned by DD (Danish Decommissioning). The reactor was a thermal homogeneous reactor with an output of 2 kW, see Figure 3. The fuel was 19,9 % enriched uranium in the form of uranyl sulfate dissolved in light water. The core comprised a spherical vessel of stainless steel having a diameter of 0,32 m.

Some features and findings are as follows:

- Existing records have been compiled and used, including a publication in an engineering journal.
- The project has compiled information from similar facilities by literature studies, plant visits and by using consultants.
- The approach has been to use the summation method for calculation in combination with a weighing scheme for the complexity and difficulty of each task.
- The PRICE computer code from UKAEA has been used, and the experience is that it is very suitable for the purpose

- For the calculations, the buildings are broken down into “components” which may have up to 15 degrees of complexity. In addition there is a task classification with three different levels.
- The experience is that work has been carried out pretty much according to plan.

The TRIGA research reactor in Finland

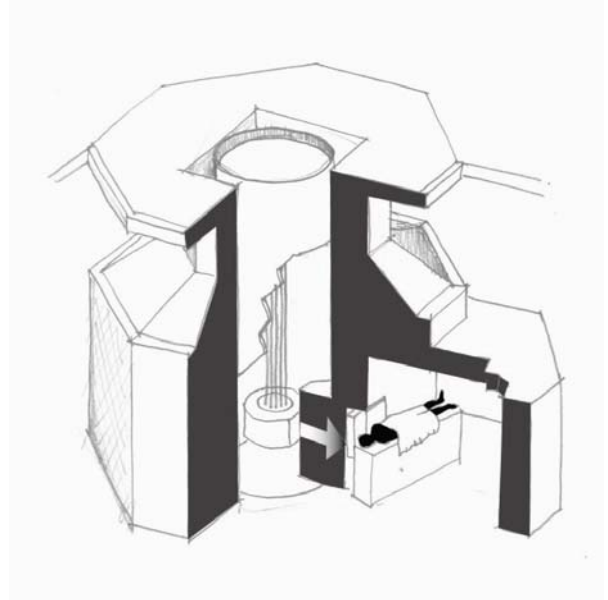


Figure 4. The TRIGA research reactor in Finland. It is being used for boron neutron capture therapy.

The TRIGA research reactor at VTT in Finland has been in operation since 1962. The uranium fuel is enriched to 20 % and it is moderated by light water. The power output is 0,25 MW. The main purpose of the present operation is Boron Neutron Capture Therapy. The overall design of the reactor is shown in Figure 4. Planning for decommissioning including submission to the Authorities of cost estimates is required under Finnish law. Much of the material for this work is obtained from the circle of present and previous owners of TRIGA reactors.

Some features and findings are as follows:

- The TRIGA reactors belong to a stage in the nuclear technology development when design features were becoming generic or standardized and many reactors were manufactured with similar designs.
- There is an established co-operation between the various owners regarding operation and maintenance of these reactors. This co-operation is being extended to decommissioning and dismantling and thereby also to cost calculations.
- Detailed descriptions of such projects including experiences made and lessons learned are available in the open literature, see e g [17].
- Such information together with careful planning has helped in grossly meeting the various targets set at similar facilities.[17]

DISCUSSION AND FINAL COMMENTS

The legacy associated with the development of nuclear technology in the Nordic Countries amounts to a few hundred M€. Generally, an environmental commitment may be the obligation of the owner and operator of a facility. However, in the present case, there is a general understanding and consensus that the parties that are benefiting (Finland and Sweden) or were intended to benefit (Denmark and Norway) from the research should assume a corresponding financial role.

Thus, there is a joint responsibility between the plant owners/operators and the Government in that timely and expedient decommissioning be carried out and that the planning and execution of the work be performed under public insight in a transparent manner.

Actually, these obligations to the society financing the decommissioning work go hand in hand with the planning and cost estimation that is required from a rational and strictly industrial perspective as described in the bulk of this paper.

In this way, sufficient but not superfluous funding may be identified and allocated in such time that the decommissioning project can be carried out in accordance with all of the health and environmental as well as the technical prerequisites.

It is important that this process be cherished and nourished by the parties concerned so that mutual trust based on mutual respect and understanding for the various tasks and roles be earned and accumulated. It may take decades to build such true confidence based on actual performance. Shortcomings in this regard are not actually affordable since they might lead to (perhaps sudden and rapid) loss of confidence.

The present work is a clear demonstration of the ambition and determination among the financiers and participants in the present project to find such a common approach for an efficient planning and execution of decommissioning as well as an open and transparent process leading to it. A key issue in this regard is the financial planning and the appropriate management of the issue of cost calculations at early stages.

High quality cost estimates will enable the following:

- 1 The funding will be in balance so that future undertakings can be carried out without any delays, thus maximizing the benefits to health and environment and to the society.
- 2 There will be less room for overcompensation since the principle of financing of the various activities will be based on good and sound cost estimates, thus keeping the costs to the society to within controlled limits.

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