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RADIATION DOSE OPTIMISATION IN THE DECOMMISSIONING PLAN FOR LOVIISA NPP

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ABSTRACT

Finnish rules for nuclear power require a detailed decommissioning plan to be made and kept up to date already during plant operation. The main reasons for this "premature" plan is, firstly, the need to demonstrate the feasibility of decommissioning, and, secondly, to make realistic cost estimates in order to fund money for this future operation. The decommissioning plan for Loviisa Nuclear Power Plant (NPP) (2x445 MW, PWR) was issued in 1987. It must be updated about every five years.

One important aspect of the plan is an estimate of radiation doses to the decommissioning workers. The doses were recently re-estimated because of a need to decrease the total collective dose estimate in the original plan, 23 manSv. In the update, the dose was reduced by one-third. Part of the reduction was due to changes in the protection and procedures, in which ALARA considerations were taken into account, and partly because of re-estimation of the doses.

In the re-estimation emphasis was put on those works that seem to cause the highest dose contributions, because these will in some cases also yield the biggest reductions. The main means for reducing the doses were addition of shielding and changes in work procedures. For instance, work with activated components cause 4.4 manSv (reduced by 3.4 manSv), and with contaminated components 4.0 manSv (reduced by 1.4 manSv). The most significant dose reducing actions were introduction of additional shielding into the RPV during disassembly of the surrounding structures, and adding shielding to the dummy fuel assembly containers and operator positions in addition allowing for increased decay time.

There is still potential for further ALARA-based dose reduction. The problems with this are, however, greater, because of the uncertainty in the actual radiation conditions at the plant at the time of decommissioning, and also because of incomplete knowledge of activity levels. An outline of further optimisation work is discussed, and guidelines for a methodology are given.

INTRODUCTION

There are four NPP units in operation in Finland. The Loviisa NPP consists of two PWR units of net capacity 445 MW. The reactor plant is of Russian VVER-440 design, but a considerable part of the plant differs radically from VVER-440 plants in Eastern Europe. One main basic difference is safety, for which normal Western standards were adopted from the beginning. This is reflected in many features of the plant. For example, the plant has an ice condenser containment based on Westinghouse design. On the other hand, the basic Russian design can be seen e.g. in the primary circuit layout, with six loops and horizontal steam generators, and in a certain complexity of e.g. process systems, with lots of spare capacity, a large number of components, etc. This has certain implications for decommissioning.

The units were commissioned in 1977 and 1980. Operation has been successful with typical load factors around 85-90%. It is expected that problems encountered can be handled in a positive way, and that operation in the future will not differ significantly from what it has been until now. It is also probable that no major changes will take place in the radioactivity and radiation conditions, although the behavior of the two units is quite different in this respect.

The spent fuel has so far been exported to Russia after being stored at the plant. Intermediate and low-level waste is stored at the plant, and will eventually be placed in an underground final repository at the site. The repository is being built at present. The decommissioning waste will be disposed of in the same repository, which will be enlarged at the time of decommissioning.

The general waste handling philosophy in Finland is that waste handling costs are taken into account during the operation of the plants and included in the price of the energy produced. The basic arrangement is defined in Finnish legislation, especially the Nuclear Energy Law, and clarified elsewhere. The decommissioning cost estimates may be more or less conservative, and it is therefore in the interest of the utility to have a detailed, plausible decommissioning plan, in order to be able to estimate and keep up-to-date the costs involved with a small error margin.

The decommissioning is planned to take place at around 2010, after about 30 years of operation. The decision and the final decommissioning plan will be made only when the technical and economical life of the plant is coming to an end. It is of course possible that the lifetime of the plant will be extended, if it proves to be economically feasible.

DECOMMISSIONING PLAN

The first decommission plan for Loviisa /1/ was completed in 1987. It describes in great detail a feasible way of dismantling the plant and of depositing and isolating the radioactive waste into the final repository on site. It is of course realized using technology of today, keeping in mind some probable developments in decommissioning techniques when planning the procedures. It is based on the concept of almost immediate dismantling without utilizing decay, dismantling of main components without cutting into smaller pieces, and leaving the non-active parts of the plant mainly intact on site. The reactor pressure vessel will be removed in one piece, placed on a transport vehicle and transported into the final repository, where it will serve as a container for the reactor internals. These will be transported in a shielding cylinder. Other large components, such as the steam generators, are also removed in one piece. Other activated or contaminated material will be cut into manageable pieces and placed into special shielded containers, depending on their activity.

The total volume of the waste produced is about 13000 m^3.

ORIGINAL DOSE ESTIMATES

The total dose estimate obtained in the original decommissioning plan was 23 manSv. This number is based on addition of a large number of dose components, some of which could be evaluated rather reliably. Other components were not very accurate. Some were even rough estimates or educated guesses. In the first attempt to arrive at a plausible number it was essential to study the distribution of doses, and in this respect the original plan serves its purpose rather well. The absolute value of the total dose was of less interest at this stage, because it was well recognized that the estimate contains large uncertainties both due to approximate definition of the work procedures (compared to what they actually will be), incomplete knowledge of the radioactivity and radiation conditions of some parts of the plant, uncertainties in how the activity levels will develop in the future, rough activation estimates of the main components without much verification based both on limited information on exact material composition and on neutron field distributions, uncertain dose estimates for complicated geometries and so on. In addition, enough attention was not given to individual doses, dose distributions and dose limits, but mainly on the collective doses irrespective of the details of how they are generated.

The Finnish Centre for Radiation and Nuclear Safety (STUK) required in their statement additional studies to be made on the possibilities to decrease the radiation doses. Such a study was initiated in 1991.

LOWERING AND RE-ESTIMATION OF DOSES

The re-evaluation of the doses concentrated both on reconsidering some of the original dose projections, partly because some new information and more sophisticated analytical methods were available, and on studying the possibilities to improve work procedures, protection and other factors, which have an influence on the doses. In a broad sense an optimisation approach was taken to the second part of the problem.

In the following an overview is given of radiation doses and dose reduction efforts for some important stages of decommissioning and types of activities involved.

Preparing for Decommissioning

The main dose-causing activities during the preparation stage are

- unsealing of the reactor, defuelling,
- flushing of process systems associated with primary circuit,
- removal of filters (main coolant pump sealing system, ventilation, off-gas treatment),
- radiation surveys,
- fuel handling,
- decontamination of primary circuit.

Most of these operations are well known, because they are directly based on normal outage operations. No special dose reducing actions have been taken. The main contributions are from radiation surveys (0.21 manSv) and reactor operations (below 0.1 manSv). The survey value is the most difficult one to estimate, and it is possible to apply optimisation to it in planning once the survey program is specified, and in addition when it is carried out.

The preparation stage causes 0.3 manSv, which is a reduction of 1.1 manSv compared to the original estimate. The reduction is due to more careful evaluation.

Activated Components

In the re-evaluation attention is mainly paid to the most important activated components and structures based on the estimate of the original plan that these cause 82% of the activated component doses. These are

- dismantling, temporary storage, transportation and final storage of the reactor pressure vessel (RPV),
- packing, transportation and final storage of the "dummy" fuel assemblies (these are inactive fuel element-like components replacing the outermost layer of fuel assemblies in the core in order to decrease neutron embrittelment of the RPV),
- disassembly, packing, transportation and final storage of the reactor biological shielding.

For these a number of dose reducing actions have been proposed, mainly based on ALARA considerations.

Dismantling of the RPV

During dismantling of the RPV most work is done in the vicinity of the loop nozzles. The main radiation sources are the loops, the activated and contaminated inner surface of the RPV above the water level and the activated RPV material at core level. The following changes in work procedures were proposed in order to save dose:

- the loops are cut at the upper nozzles and shield disks are welded to the nozzles before dismantling of the shielding around the reactor,
- the remaining parts of the loops, e.g. the lower nozzles, could be shielded in an equivalent way depending on the situation and need ,
- temporary shields are used during the welding,
- as much of the work as possible in the nozzle area is done prior to disassembling the shielding around the reactor.

Radiation from the inner surface of the RPV can be decreased significantly by installing a shield consisting of a massive shielding cylinder or possibly separate massive plates into the RPV. A preliminary optimisation analysis for this indicates an optimal thickness of 4 cm, but up to 10 cm could be installed.

Shielding and Transportation of the RPV

The RPV will be partially enclosed into a concrete shield of thickness 300 mm, which decreases the dose rate at the core level to about 1.5 mSv/h. This served as a base case for the optimisation study. The main variant is to embed 6 cm of steel into the concrete at the core elevation to decrease the dose rate locally to 0.3 - 0.4 mSv/h.

During lifting the RPV the only shield is the cylinder. During transportation on a special vehicle, additional shielding can be added to protect the driver. Lifting the RPV into its final storage silo is partly done remotely.

The total dose caused by these operations is about 0.5 manSv. The dose saved by changing the shielding cylinder is 0.12 manSv.

Reactor Internals

Removal and transportation of the reactor internals is in principle a routine operation, because they are normally transported in a steel shield (not submerged under water). The dose expenditure is low, about 0.04 manSv.

Dummy Fuel Assemblies

The dummy assemblies belong to the most severely activated components at the plant. They are transferred from the reactor into a pool. From there they are lifted one at a time into a concrete transport container, using a steel shielding container. The transport container is transferred into the final repository, and the assemblies are again lifted one at a time into the RPV using the steel cask.

To lower the dose optimally a 6 cm increase in the original 25 cm thickness of the steel container wall is necessary. A more important reason is the individual dose limit. In addition, some improvement is achieved by transferring the assemblies in the right order and utilizing the delay between decommissioning of the two units for additional cooling. The Lo1 assemblies can be stored in the Lo2 RPV.

Control Rod Absorbers

Absorber Connection Rods and Other Activated Core Components

Activated parts have been dumped into a temporary shielded storage silo. Dismantling the storage, which consists of separate steel tubes embedded in concrete, can be done in several ways, none of which is easy. The main improvement is based on arranging the contents into the final storage container in such a way that the most heavily activated parts are put in the middle.

Biological Shield

The activation of the biological shield was re-estimated using more sophisticated analytical tools, better knowledge of the composition and a few radiation level values measured inside the shield. The dismantling consists of eight main phases, of which nos. 3, 4 and 6 cause the largest doses. These are

- cutting of the reactor heat shield,
- cutting of the dry serpentinite concrete shield,
- cutting of the structural concrete at around core elevation.

Dismantling of the biological shield is very work intensive, and therefore even quite low dose rates can cause significant doses.

The total re-estimated dose burden is 0.089 manSv from cutting, 0.044 manSv from packing, 0.095 manSv from transportation and 0.095 manSv from the repository. Although the single components changed significantly from the original plan, their sum did not. The total dose is 0.3 manSv. No changes in the original arrangements (performing some operations under water, temporary shielding above the reactor pit, waste containers) were proposed, except pointing out the need to consider the order of packing.

Dose Distribution in Dismantling Activated Material

The dose components caused by dismantling activated components are presented in Table 1.

Table 1. Dose components (manSv) caused by activated material

	Dismantling	Packing	Transport	Repository	Sum
Reactor pressure vessel	0.86	0.10	0.07	0.26	1.29 (-1.12)
Reactor internals	-	0.02	-	0.02	0.04
Dummy fuel assemblies	0.003	0.067	0.02	0.121	0.21 (-0.55)
Control assemblies	-	0.04	0.07	0.05	0.16
Small activated parts	0.01	0.14	0.01	0.02	0.18
Reactor heat shield	included in the biological shield doses				(-0.03)
Biological shield	0.089	0.044	0.095	0.095	0.32 (-0.04)
Sum					2.20 (-1.74)

Contaminated Material

Doses caused by dismantling contaminated equipment are estimated to be of the same order of magnitude as those caused by activated components. Typical for contaminated equipment are the low dose rates in many cases, in combination with a large volume of very slightly contaminated waste. There are also single highly contaminated components, e.g. the loops and the primary coolant purification system heat exchangers. The uncertainties are very large, until a complete survey of the actual situation is done prior to decommissioning. Contamination levels are hard to predict.

The main dose saving improvements to be utilized, are

- use of various remotely controlled equipment,
- flexible use of mobile local shields,
- optimising the order of dismantling according to activity and dose rate levels,
- decontamination of single systems or components (potential method).

Decommissioning Doses

Table 2 shows the projected dose contributions from main types of activities for both units, and the dose savings compared to the original plan.

Table 2. Distribution of total decommissioning doses (manSv)

	Lo1	Lo2	Lo1 & Lo2
Preparation works	0.3 (-1.1)[a]	0.3 (-1.1)	0.6 (-2.2)
Decontamination of primary circuit	0.06	0.06	0.12
Dismantling			
- activated components	2.2 (-1.7)	2.2 (-1.7)	4.4 (-3.4)
- reactor building contaminated components	2.0 (-0.7)	2.0 (-0.7)	4.0 (-1.4)
- other contaminated components			2.5 (+0.65)
IVO staff			2.1 (-0.8)
Sum			13.7 (-7.2)
		+10%	1.4
Total			15.1 (-7.9)

[a] Values in parenthesis are changes relative to the original plan

OUTLINE OF FURTHER DOSE OPTIMISATION

The re-evaluation of doses included elements of ALARA-based reconsideration of operations and procedures, and of some specific optimised improvements. Optimisation was not, however, carried out to the extent possible. One reason for this was the lack or incompleteness of some information.

In the updated dose estimate special attention was given to the largest dose components. It was felt that these had the largest potential for decreasing the doses. Although this is not necessarily the whole truth, and in addition actually is not consistent with the ALARA principle, no big effort can be made to optimise small dose components. Instead, general procedures which are efficient in further lowering many already low dose components should be looked for. For instance, the gain from covering the most significant sources during dismantling of large, slightly contaminated process systems should be estimated in a systematic way, although there does not seem to be any apparent reason for this, based on the low dose rates.

Optimisation must be based on realistic dose estimates, which are derived from realistic values for all relevant factors affecting the doses. Therefore, such optimisation should be done at an appropriate stage. There are only limited possibilities for this as long as the necessary information does not exist.

It is still necessary to improve various single dose estimates as part of the optimisation. At the present stage they are based on a variety of information, such as

- gross collective and individual dose experience,
- conclusions drawn by analogy from single dose experiences,
- crude conceptual models for collective dose components.

It is useful to include some explicit measure of uncertainty in the various dose component estimates, in order to see more clearly where there is need for improving the quality of the information.

For optimisation purposes it may be advantageous at some later stage to systematically generate and consider several feasible options for performing single operations. Such options have to some extent been considered in the present re-evaluation, but not very explicitly.

In general more formal ALARA studies should be made, in order to restrain from going too far in dose reduction. Additional dose reductions can be required, but good reasons based on other considerations than pure radiation safety should be given explicitly.

A special data base should be established at an early enough stage, in order to collect information useful in the decommissioning planning, which is obtained as by-products in other activities. It is probably more economical to gather such data during a long period of operation than by brute force in a short time. This would gradually improve the quality of the dose estimates and dose planning.

It has still not been possible to consider in enough detail the role of individual exposures. Inclusion of such considerations will introduce additional motives for improving protection and lowering doses because of the mere expenses caused by a possible need to expose a larger number of persons. Rotating workers in such a way has multiplicative effects on costs, because of the work arrangements, administration, education and training and even employing more people. These considerations may well be treated on a cost-benefit basis.

CONCLUSIONS

It must be noted that the re-estimation of doses is still based on the original assessment. The estimated dose savings and the increase in some components should be seen in relation to this. There are still many open questions regarding the absolute level of the doses, although there is no reason to believe that the actual doses would differ much from the estimated ones, if decommissioning is performed according to the plan.

A quite realistic estimate of the dose savings relative to the original plan is 7.9 manSv, leading to a total collective dose of 15.1 manSv for both units.

The role of operative radiation protection during the actual decommissioning has not been fully utilized in the planning. Depending on the actual conditions and needs, operative radiation protection has available an extensive repertoire of means to decrease doses in single works. By acting reasonably and applying normal procedures of radiation protection and health physics based on ALARA considerations, essential dose savings can probably be achieved.

There is still potential for ALARA-based dose saving efforts. The main obstacle to this at present is that all necessary information is not available. In later re-estimations additional improvements in dose reduction will be possible.

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