SKI Report 2007:19

Research

An Applied Study of Implementation of the Advanced Decommissioning Costing Methodology for Intermediate Storage Facility for Spent Fuel in Studsvik, Sweden with special emphasis to the application of the Omega code.

Dr. Kristina Kristofova
Mr. Marek Vasko
Dr. Vladimir Daniska
Mr. Frantisek Ondra
Mr. Peter Bezak
Mr. Staffan Lindskog

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SKi

SKI perspective

Background

The nuclear power utilities must under the Act on the Financing of the Management of Certain Radioactive Waste etc. (1988:1597), sometimes referred to as the "Studsvik Act", fund 0,3 öre[1] per kWh produced by utilisation of nuclear power. The funds are held by the Swedish Nuclear Waste Fund. The Swedish parliament has decided that this fee shall cover all expenses for the decontamination and decommissioning of older historic waste that stems from Swedish nuclear installations and research reactors within the original Swedish Nuclear program. The task to inject enough capital into the Swedish Nuclear Waste Fund is vital and crucial for the long-term sustainability of the Swedish financing system. Therefore it is of prime importance that provisions to the fund reflect the future authentic costs of performing the planned tasks to decontaminate and dismantle these older nuclear facilities.

Purpose of the project

The aim of this applied study has been to describe in a systematic way an appropriate methodological sequence for cost estimation of crucial parameters in decontamination and decommission processes. The work has been limited to older nuclear installations and facilities. Furthermore, it may be envisaged that the process of estimating the parameters of decommissioning is one of the main issues in preparatory phases of decommissioning processes. The main aim of the presented project has been to present a comprehensive procedure for how to prepare a file of fundamental and qualified input data in the earlier planning phases of decommissioning and capital budgeting of major decommissioning projects. These parameters include inter alia costs, exposures, duration times, amounts of waste, manpower, personnel and equipment needed

Nevertheless, 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 under the Studsvik Act**.**

Results

The study demonstrates that it is possible to enhance and extend the present knowledge basis for cost estimates by describing the different necessary steps in a process by referring to an authentic nuclear installation.

The report is to be seen as part of an active learning process; that ultimately may stimulate to improved cost calculations of smaller older nuclear installations by using tools of advanced costing methodology.

[1] Approximately 0,03 European cents.

The study illustrates that an efficient technical planning is obtainable. 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 more prudent and efficient cost estimations. The next step in this process would be to classify the different cost items according to a proposed standard list structure and validate the basic data. Thereby, enable us to create a base for comparative cost studies with indicative and indirect validation of the estimated cost for decontamination and decommission of a particular nuclear installation or sets of nuclear installations.

Effects on SKI work

SKI will be able to draw inferences from this study. This is especially valid for the ongoing monitoring of yearly cost estimates that are presented by the companies AB SVAFO, Vattenfall AB and Studsvik Nuclear AB. The study will therefore support the present review process regarding estimated dismantling costs of nuclear installations located at the Studsvik site and Ågesta.

Project information

At SKI Staffan Lindskog has been responsible for supervising and co-ordinating the project. At Deconta a/s Marek Vasko has been responsible for the steering and realisation of the research project. Staffan Lindskog, Marek Vasko and Vladimir Daniska are responsible for the disposition of the report. Crucial parts of the analysis have been done by Kristina Kristofova, Peter Bezák and Frantisek Ondra.

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Dr. Vladimir Daniska [1]
Mr. Frantisek Ondra[1]
Mr. Peter Bezak [1]
Mr. Staffan Lindskog [2]

[1] DECOM Slovakia, spol. s.r.o.
J. Bottu 2
SK-917 01 Trnava

[2] SKI-Statens Kärnkraftsinspektion
Swedish Nuclear Power Inspectorate
Klarabergsviadukten 90
SE-106 58 Stockholm, Sweden

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ABSTRACT

The presented study is focused on an analysis of decommissioning costs for the Intermediate Storage Facility for Spent Fuel (FA) facility in Studsvik prepared by SVAFO and a proposal of the advanced decommissioning costing methodology application. Therefore, this applied study concentrates particularly in the following areas:

1. Analysis of FA facility cost estimates prepared by SVAFO including description of FA facility in Studsvik, summarised input data, applied cost estimates methodology and summarised results from SVAFO study.
2. Discussion of results of the SVAFO analysis, proposals for enhanced cost estimating methodology and upgraded structure of inputs/outputs for decommissioning study for FA facility.
3. Review of costing methodologies with the special emphasis on the advanced costing methodology and cost calculation code OMEGA.
4. Discussion on implementation of the advanced costing methodology for FA facility in Studsvik together with:
   - identification of areas of implementation
   - analyses of local decommissioning infrastructure
   - adaptation of the data for the calculation database
   - inventory database
   - implementation of the style of work with the computer code OMEGA.

ABSTRAKT

Predkladaná štúdia je zameraná na analýzu parametrov vyraďovania pre Medzisklad vyhoreného paliva (FA zariadenie) v Studsviku, ktoré pripravila firma SVAFO a súčasne obsahuje návrh pre použitie pokročilých metód stanovovania parametrov vyraďovania. Preto sa táto štúdia špeciálne zameriava na nasledujúce oblasti:

1. Analýza štúdie SVAFO pre stanovenie nákladov na vyraďovanie FA zariadenia vrátane popisu FA zariadenia v Studsviku, zhrnutých vstupných údajov, použitej metodiky stanovenia nákladov na vyraďovanie a zhrnutých výsledkov zo štúdie SVAFO.
2. Diskusia k výsledkom SVAFO štúdie, návrhy pre použitie dokonalejšej metodiky stanovovania nákladov na vyraďovanie a zlepšenie štruktúry vstupných/výstupných údajov pre štúdiu vyraďovania FA zariadenia.
3. Prehľad metód stanovovania nákladov na vyraďovanie s dôrazom na pokročilé metódy stanovovania parametrov vyraďovania a popis výpočtového prostriedku OMEGA.
4. Diskusia k implementácii pokročilých metód stanovovania parametrov vyraďovania pre FA zariadenie v Studsviku zahŕňajúca:
   - identifikáciu oblastí implementácie
   - analýzy lokálnej infraštruktúry pre vyraďovanie
   - prispôsobenie údajov pre výpočtovú databázu vyraďovania
   - databázu inventáru vyraďovaného jadrového zariadenia
   - implementáciu štýlu práce s výpočtovým prostriedkom OMEGA.

1. ABBREVIATIONS

CDE	Collective Dose Equivalent
FA facility	Intermediate Storage Facility for Spent Fuel facility in Studsvik
PSL	Proposed Standardized List of Items for Costing Purposes in Decommissioning
RAW	Radioactive Waste
WBS	Work Breakdown Structure

2. INTRODUCTION

A project “An Applied Study of Implementation of the Advanced Decommissioning Costing Methodology for Intermediate Storage Facility for Spent Fuel (FA facility) in Studsvik, Sweden with special emphasis to the application of the OMEGA code“ is the result of Swedish Nuclear Power Inspectorate (SKI) cooperation with DECOM Slovakia in 2005. This project continues on the findings and suggestions that were presented in the previous successful pilot SKI-DECOM project in 2004 on detailed analysis and cost estimates of decontamination and decommissioning with an emphasis to derive cost functions for alpha-contaminated material.

The aim of the presented study is to perform work on applied study within the field of decommissioning cost estimates methodology used for older nuclear facilities at the Studsvik site in Sweden. Hence the study provides an analysis of decommissioning costs for the FA facility in Studsvik prepared by SVAFO and a proposal of the advanced decommissioning costing methodology application. The following project work packages (WP) were specified in the Letter of Authorisation:

- **WP 1:** Analysis of FA facility cost estimates prepared by SVAFO (review of methodology, inventory and calculation data, cost structure, results)
- **WP 2:** Discussion of results of the analysis and proposals for upgrading the cost estimates for FA facility
- **WP 3:** Review of the advanced costing methodology proposed for developing the upgraded cost estimates for FA facility in Studsvik
- **WP 4:** Discussion of aspects of implementation of the advanced costing methodology for FA facility in Studsvik (review of inventory and input calculation data, methods for their development and proposal for step-by-step implementation of the advanced decommissioning costing methodology)

In order to enhance and upgrade the results from SVAFO decommissioning study where traditional comparative costing methodologies were used, the presented study proposes the application of the advanced costing methodology with the following features:

- The methodology implements the standardised cost calculation structure for decommissioning issued commonly by OECD/NEA, EC and IAEA.
- The costing methodology relays directly on the real inventory of the nuclear installation to be decommissioned (structure, masses, materials, contamination levels, nuclide composition and others). It means to use the generic costing methodologies and not the comparative costing methodologies.
- The costing methodology implements directly also the local factors like labour costs, decommissioning infrastructure including the technologies for dismantling and decontamination, treatment, conditioning and disposal of waste and other technologies for decommissioning.
- The costing methodology implements the elements which model the real material and radioactivity flow in entire decommissioning process; the radio-nuclide flow should be nuclide resolved and the radioactive decay for each nuclide should be respected.
- The methodology has a “multiple option” character, it means that more representative decommissioning options should considered in order to evaluate all possible scenarios of decommissioning.
- Each decommissioning option should be calculated, optimised and evaluated individually and the most optimal option should be selected based on multi-attribute analysis.

When applying these basic principles the results can be achieved, which are reasoned, transparent, traceable and verifiable to the lowest cost elements. The costs are then directly comparable for various decommissioning projects and for various countries.

The pre-requisite for implementation of this advanced generic costing methodology is also the developing the inventory database and calculation databases with structures which support and enable the using the advanced costing methodology.

The advanced decommissioning costing methodology with these properties was developed recently in the company DECOM Slovakia including the computer code OMEGA which fully implements the above identified features of the advanced decommissioning costing methodology.

The implementation of the advanced costing methodology and also the use of the computer code OMEGA is country or decommissioning project specific it means that following aspects should be considered:

- local decommissioning infrastructure should be analysed and implemented into the decommissioning scenarios in order to be able to develop/evaluate relevant decommissioning options, specific for the country and for the nuclear installation to be decommissioned
- local unit factors and other country specific calculation data should be implemented into the calculation database
- inventory database for nuclear facility to be decommissioned should be developed with the structure relevant for the advanced costing methodology.

When respecting these implementation principles, the advanced costing methodology and also the computer code can be used practically for each nuclear facility or country.

3. ANALYSIS OF FA FACILITY COST ESTIMATES PREPARED BY SVAFO

The AB SVAFO company is responsible for future decommissioning of nuclear facilities Ågesta and Ranstad at Studsvik,. The SVAFO company elaborated a study on decommissioning cost estimates for the Intermediate Storage Facility for Spent Fuel (FA) facility in Studsvik. The chapters below provide an analysis of this SVAFO study in the following sequence:

- General description of FA facility in Studsvik
- Summary of input data on FA facility used for the purpose of SVAFO decommissioning cost estimates
- Information on SVAFO cost estimates methodology applied for FA facility together with a commentary
- Summarised SVAFO decommissioning study results.

3.1 GENERAL DESCRIPTION OF FA FACILITY IN STUDSVIK

3.1.1 Purpose and history of facility

The FA facility was designed and used as an intermediate underwater storage facility for spent fuel from the Ågesta reactor. It was designed and built during 1962-1964 [1]. As all fuel from Ågesta has been transferred to CLAB, the facility may be used for other purposes such as storage of spent fuel from other reactors, or for storage of other radioactive materials [2]. Stored fuel has originated from R1 reactor in KTH Stockholm, R2 an R2-0 reactor in Studsvik and reactor in Ågesta.

Currently, the facility is being used only for the temporary storage of spent nuclear fuel from the research reactors R2 and R2-0.

3.1.2 Location and general description of facility components

FA facility is located at the Studsvik site. More accurate location is shown on picture of the Studsvik site in Fig. 3.1.

Fig. 3.1 Location of FA facility within the Studsvik site published on http://www.studsvik.se/images/view2.jpg

This figure was provided but has been redacted from the final report on grounds of physical security.

The FA facility comprises three storage basins. In the cellar floor there are located the process equipment, tanks, ion-exchangers, heating and compressor units and technological piping. Three store basins, offices and changing rooms are located on the ground floor. The storage basins are constructed as monolith reinforced concrete unit lined with epoxy painting. Their depth is 8.2, and the diameter is 3.8 meters. Upper floor includes ventilation equipment and de-ionized water storage tank.

3.1.3 General information about stored RA waste and radiological situation

There are 111 fuel assemblies stored in one of storage pools, which comprises 118 kg of spent fuel [2]. This spent fuel has to be removed and transported to other storage facility before the start of decommissioning work.

Co-60 is expected to be a main contaminant of FA facility.

Radioactive contamination of process equipment is expected mainly on the internal area of pipes, tanks and other components and much less on exterior surfaces. The surface dose rates on pipework in the facility cellar vary between 0.01 and 2mSv/h. These values indicate the need of decontamination for a great portion of equipment surfaces to meet the release criteria according to SSI regulation SSI FS 1996:2.

Radioactive contamination of building structures can be found in significant levels mainly in the restricted areas with components (piping, tanks) or in places with more or less radioactive material free handling. Surfaces in the hall have a yellow classification, which implies activities of between 40 and 400 kBq/m^2 (β,γ) and between 4 and 40 and 400 kBq/m^2 (α).

In the case of decontamination basin it is assumed that activity can occur behind the lining (10% of the surface to a depth of approx. 2 cm).

Within the fuel storage basins the concentration of activity has been of order of MBq/m^3. At the same time it is assumed those internal wetted surfaces are penetrated by radioactivity (10% of the surface to a depth of approx. 5 cm). These surfaces need to be decontaminated or removed respectively.

For estimating contamination levels for components, the SVAFO study uses a method of conversion factors between surface dose rate measurements and specific activity of given component.

3.1.4 Planned decommissioning scope

Decommissioning of FA facility comprises dismantling and demolition of all solid materials inside the external boundaries of the building and an adjacent washing-down area, including necessary decontamination of contaminated equipment and building structures surfaces.

Dismantling of equipment includes piping and components of all systems, electrical and control cables, handling equipment and machinery and insulations.

Demolition of building involves removal of building structures to 0.5 m below surface level, with removing of all arch works (ceilings) to eliminate air pockets and avoid of risk for possible future cave-in and settling. That means all building structures such as doors, shielding doors, windows, exterior coverings, embedded materials, platforms, steps, footplates, machine and crane rails will be removed.

3.2 FA FACILITY INPUT DATA USED FOR SVAFO COST ESTIMATES

There are several input data on FA facility used for decommissioning cost estimates within SVAFO study. These input parameters describe FA facility, its building structure (object-floor-room) together with room dimensions. However the main part of input data is represented by the database of FA facility equipment, distributed in particular rooms. Each database item is characterised by the following parameters: quantity, category of equipment, mass, sort of material, typical dimensions of given equipment, volume and mass of particular equipment components. Listed technological equipment are divided into two groups – active and inactive. The SVAFO study presents also summary tables on mass of corresponding equipment categories for active and inactive equipment.

As it was already mentioned in chapter 3.1, FA facility is formed by main building with three floors: cellar, ground floor and first floor. The list of all FA facility rooms allocated to the floors is given in Tab. 3.2-1 below.

The cellar floor contains sixteen rooms (room numbers 0.01 – 0.16 in Tab. 3.2-1) comprising active as well as inactive process equipment such as heating and compressor units, electricity and communication facilities, tanks and ion-exchangers.

The ground floor contains seventeen rooms (room numbers 1.01 – 1.17 in Tab. 3.2-1) which are occupied mainly by storage basins, offices and changing rooms. Part of comprised technological equipment in storage hall is active but most of other rooms comprise inactive equipment.

The upper floor contains three rooms (room numbers 2.01 – 2.03 in Tab. 3.2-1) containing ventilation equipment, together with a deionised water storage tank. Active equipment are placed only in the room 2.02, other rooms contain inactive equipment.

Distribution of equipment in particular rooms of FA facility is enclosed in SVAFO study Appendix 3.

This figure was provided but has been redacted from the final report on grounds of physical security.

In Tab. 3.2-1, for rooms that are assigned to be filled (0.5 m below ground level) there are listed dimensions (length, width, height). SVAFO study contains tables with additional input data for these rooms, such as wall area, floor area, ceiling area and room volume (included in Appendix 6 and Appendix 7 in SVAFO study).

The SVAFO study presents an input technological database of operational technological equipment and building equipment. The balance of technological equipment summarized in database is based on the above mentioned object – floor – room data structure. Technological equipment has been split into two categories: potentially active and inactive. The following table Tab. 3.2-2 provides a summary of active and inactive components of technological equipment in FA facility. Numeric values have been taken from SVAFO study database, which also includes estimated volumes of given equipment.

Tab. 3.2-2 Total active and inactive technological equipment in FA facility

Technological equipment	Mass [kg]	
	Active components	Inactive components
tanks	2 780	1 800
sheet cladding	1 510	-
pipes, valves	1 117	2 586
pipe supports	279	646
pumps	120	235
ventilation equipment	80	1 756
heating system	100	1 917
porcelain	15	20
shielding casks + other	25 897	-
electrical cabinets	-	2 331
cable supports	-	103
cabling	-	398
motors	-	410
insulation	-	1 478
fans	-	580
steel ducting	-	759
aluminium ducting	-	540
insulation ducts	-	624
handling machine	-	13 050
service gantry	-	3 000
travelling crane	-	25 000
Total components	**31 919**	**57 234**

Based on technological equipment database in SVAFO study, the summary of active and inactive material categories in FA facility is presented in table Tab. 3.2-3 below. Volumes of technological components are estimated using available installation drawings, manufactures catalogues and normal practice.

Tab. 3.2-3 Material categories of technological equipment in FA facility

Material category, active components	Mass [kg]	
	Active components	Inactive components
Steel	31 474	50 512
Plast	180	33
Electrical cabinets	20	2 331
Porcelain	15	20
Cooper		212
Aluminium		654
T-insulation		2 103
Cable runs		103
Cable supports		398
Motor		410
Total	**31 919**	**57 234**

Input building equipment characterization in SVAFO study is limited to the description of FA facility object, with its floors and rooms. Amounts of contaminated and non-contaminated building materials, such as concrete and steel are given in the form of output materials arisen from decommissioning process.

As for input radiological conditions of technological and building equipment, SVAFO study data are limited to listing of specific FA facility equipment which are considered being potentially active. According to the SVAFO study FA facility building comprises contaminated remaining of the floors, walls and ceiling surfaces including inner surface contamination of the fuel storage basins, piping and tanks. Information on radiological situation in FA facility in Studsvik used in the SVAFO study refers to other reference documentation.

The surface activity value of 10 kBq/m^2 for Co-60 is taken to be representative of the total activity (α and β/γ) on the surfaces of FA facility. Building surfaces in the hall have yellow classification (activities of between 40 and 400 kBq/m^2 for β/γ and between 4 and 40 kBq/m^2 for α). It may be necessary to remove the portions of floor surface layers to meet acceptable activity levels. The SVAFO study uses conversion factors from surface dose rate to specific activity of steel and plastic piping. An estimated conversion factor for steel piping lies between 3 and 10 kBq/kg per μSv/h. For plastic piping, the conversion factor of 20 to 100 kBq/kg per μSv/h has been estimated. Considering the limit of total 500 Bq/kg, in which a maximum of 100 Bq/kg are allowed from alpha emitting nuclides and surface dose rates in the facility cellar which vary between 0,01 and 2 μSv/, the potentially active FA facility equipment cannot be certified as inactive without extensive decontamination.

3.3 SVAFO COST ESTIMATES METHODOLOGY APPLIED FOR FA FACILITY

Current costing methodologies were developed based on experience from decommissioning of nuclear facilities with standard shutdown properties. The methodologies were then used for cost estimates for similar facilities. The unit factors, calculations formulas and other elements of cost methodologies could be applied after comparison of facilities and relevant corrections for the differences in size, inventory, radiological status, local factors and other aspects. The quality of results depends on proper adjustment of the methodology for facility conditions.

The SVAFO cost estimates methodology implement this standard costing attitudes, generally used for similar applications on the level of preliminary feasibility study. The references listed on details of the methodology were not available however from the description of the methodology presented in the study, some conclusions may be drawn. The methodology considers the standard cost categories:

Activity-dependent costs, related to the extent of hands-on were applied for decommissioning activities which are listed in chap.3.4. The calculation relations use unit factors for 11 component categories adopted from earlier studies. No correction factors for work in radiation fields or other constraints are used for calculation of manpower. The unit factors used for decontamination of building surfaces, radiation monitoring of building surfaces and final demolition are not presented.

Period-dependent costs, proportional to duration of individual decommissioning activities, were applied for preparatory activities. The estimates of duration of individual items are used for calculation of costs for packages P1 to P8.

Fixed costs are used for some items within the group A1 to A20.

The details of the methodology for calculation of costs for items A1 to A20 is not presented, it seems to be a combination of activity-dependent costs and period-dependent cost calculation or fixed costs according the nature of the item. A general contingency of 20% is applied equally for all calculated items and also a general escalation on the level of 15% due to later use of the cost data.

As for the waste management, except transporting, storing or dumping, only minor activities are considered, like monitoring, sorting, flushing, etc. No extensive post-dismantling decontamination or more advanced treatment and conditioning methods of waste are considered. The amounts of wastes were derived from the inventory and based on operational designation of individual items and on dose rate measurements using the mass activity to dose rate conversion factors.

The structure of costs is simple and project specific. If it should be presented in standardised structure issued jointly by OECD, EC and IAEA, an additional transformation step is needed.

The costing methodology is relatively simple and could be considered as a first-stage estimate for finding the frame for cost figures for FA facility decommissioning. More detailed cost calculation would be desired which include more detailed inventory of decommissioning activities and more comprehensive waste management. The radiological aspects should be also considered in calculation of exposure and costs and also in the frame of the waste management. The aspect of multi-option attitude should be also considered, it means more options covering possible scenarios of decommissioning should be defined, calculated and evaluated.

3.4 RESULTS FROM SVAFO COST ESTIMATES FOR FA FACILITY

The SVAFO decommissioning study evaluates a direct dismantling decommissioning option applied on FA facility in Studsvik, although the starting date of this option is not precisely defined. The decommissioning project evaluated in the SVAFO study involves preparation, decontamination, dismantling, demolition, backfilling, site remediation and waste management activities including sorting, recycling and treatment of all solid and liquid radioactive material together with their storage. Three alternatives for generated waste are considered: free release of material, transport to safe repository for short-lived waste or transport to safe repository for long-lived waste. The study [1] includes the review of the above mentioned evaluated decommissioning activities in particular chapters 8.2.1, 8.2.2, 8.2.3 and chapter 9. Phases of decommissioning process of FA facility taken into consideration within the SVAFO study are as follows:

1. Cleaning of equipment, floors and walls
2. Measurement and certification of equipment, surfaces as active/non-active
3. Dismantling and removal of equipment classified as active
4. Removal of any active concrete material, activity monitoring
5. Certification of remaining building material and equipment
6. Dismantling and removal of non-active equipment
7. Demolition of the building using conventional methods

In addition to above listed activities, management of waste arisen from decommissioning, site remediation and documentation is considered.

As for evaluated decommissioning parameters, the SVAFO study presents three kinds of output parameters: costs, manpower, and amount of generated waste. These overall parameters are summarized in chapter 6 and chapter 8 respectively. More detailed parameters for specific equipment, rooms and building structures are listed in Appendixes 4, 6, 7, 8, 9 and 10 of SVAFO study. Except of these, the study presents additional parameters for estimated demolition works such as volume of building debris or volumes for technological components.

It is expected that the main sources of dose rates and radioactive aerosols will be: handling with radioactive materials, treatment and processing of radioactive materials, decontamination of process equipment surface and building surface, dismantling and segmentation of the technological equipment.

3.4.1 Decommissioning costs

Decommissioning costs in the SVAFO study are estimated for the following 3 main group of activities:

1. **Preparatory works** for ensuring of condition before begin of realization of decommissioning as documentation and drawings, facility layout, radiological survey, industrial survey, preparation of documentation, timetable, transport, site work, closure works etc.
2. **Supporting, preparatory and finishingconcluding works** including decontamination of equipment, decontamination of building surfaces and final cleaning of the localities.
3. **Realization of decommissioning work** as dismantling and demolition. The process includes preparatory and finishing works, handling of building material, recycling, dumping and back-filling of underground volume and storage of radioactive waste.

The following tables - Tab. 3.4-1, Tab. 3.4-2 and Tab. 3.4-3 show more detailed structure of presented three groups of decommissioning activities.

Tab. 3.4-1 Cost for project management, preparation and running-down

Action	**Sequential amount [MSEK]**
Preparatory work on-site to demolition	0,48
Preparation of documentation	1,08
Definition of the procurement packet	0,36
Establishing timetable	0,17
Planning transport	0,36
Planning for site work	0,30
Work during the decommissioning	2,04
Making good after decommissioning	0,60
Total sum with 20% margin for unplanned activities	**6,47**

Tab. 3.4-2 Costs for preparatory, supporting and concluding efforts

Action	Sequential amount [MSEK]
Preparatory work of decommissioning	1,29
Cost for demolition work	1,38
Decontamination of building surfaces	2,25
Concluding works	0,3
Total sum with 20% margin for unplanned activities	**6,26**

Tab. 3.4-3 Costs of the actual dismantling and demolition works

Action	Sequential amount [MSEK]
Dismantling the process equipment (11 man-months)	0,92
Crane hire, tools and other demolition equipment	1,00
Building demolition	2,83
Asbestos sanitising	0,60
Total sum with 20% margin for unplanned activities	**6,42**

Cost unit factors for building demolition are presented in Appendix 10 in SVAFO study. Each particular estimated cost unit factor depends on building category and activity

The SVAFO study assumes total costs of 19.2 MSEK as a result of FA facility decommissioning.
Total costs of 19.2 MSEK consist of the following components:

Preparatory, supporting and concluding efforts by the project group: .... 6,5 MSEK
Work performed by the project group, or order, and fees: .... 6,3 MSEK
The actual work of decommissioning .... 6,4 MSEK

3.4.2 Manpower

For dismantling activities the SVAFO study uses a system of unit factors for manpower needs, shown in table below which are depended on material category of technological component.

Tab. 3.4-4 Manpower unit factors for component dismantling

Task/type of component	Manpower unit factor kg/man-hour
Intact tanks	75
Dismantling of sheeting	25
Pipes, elbows, T-joints, reductions	10
Pipe supports	10
Pumps	20
Valves	10
Electric cabinets, instruments	50
Ventilation equipment	10
Fans	20
Components in heating systems	40
Motors	20

The more detailed review with these parameters is shown in Appendix 4 of SVAFO study. In order to compensate uncertainties in assessing the quantities of materials requiring dismantling, the SVAFO study uses 10% margin which is added onto the final sum of material quantities as compensation.

Manpower needs for preparatory works corresponding to cost items in Tab. 3.4-1 are estimated to 54 man-months. Efforts necessary for supporting activities corresponding to cost items in Tab. 3.4-2 are estimated to 6 man-months. For decontamination of building surfaces the study estimates manpower needs of 25 man-months. Efforts of 11 man-months for dismantling activities derived from manpower unit factors are considered.

3.4.3 Amount of waste

The total quantity of equipment scrap is estimated to 90 tons. The buildings materials that are to be recycled as filling are expected to amount to about 457 m^3. The total building volume is approx. 5600 m^3, of which 4660 m^3 are above ground. Since the cavities lying below ground level, that are to be filled in, amount to 936 m^3, then 479 m^3 of material must be obtained elsewhere.

Decommissioning of the process equipment is expected to yield about 58 tons (175 m^3) that are to be sent for dumping and about 32 tons (30 m^3) to be sent for storage. Particular technological equipment considered active or inactive are listed in Tab. 3.2-2.

55 tons of material from building demolition is expected to be sent for dumping, and approx. 5 tons (2 m^3) to storage (see below Tab. 3.4-5).

Tab. 3.4-5 Treatment of the demolition wastes

Subsequent management of the debris	Quantity (tons)	Volume (m3)
Storage for long-lived wastes (SFL)	-	-
Storage for short-lived wastes (SFR)	37	32
Backfilling below ground level	1,200	457
Dump for conventional wastes	113	~200
Other materials classified as inactive	-	-
Total	**1,320**	**~700**

The main portion of building structure is going to be removed to a depth of 0.5 m below surface level. In addition, demolition work also involves removal of the following equipment (before filling of remaining building structures):

- steel framing, exterior coverings, doors, windows gateways and shielding doors,
- travelling crane girders and handling machine rails,
- footings and penetrations for piping, cables and ventilation
- room fittings such as platforms, steps and handrails, footplates, fire and inspection openings
- lightning, power outlets, fire alarms and communication systems.

Building structures lying 0.5 m below ground level are going to be back-filled by building debris from realization of demolition work.

4. DISCUSSION OF RESULTS OF THE SVAFO ANALYSIS AND PROPOSALS FOR UPGRADING COST ESTIMATES FOR FA FACILITY

The chapter comments presented input data, applied cost estimates methodology and presented results of the SVAFO study. At the same time, proposals for enhanced cost estimating methodology and upgraded structure of inputs/outputs for decommissioning study for FA facility are described.

4.1 DISCUSSION ON INPUT DATA

4.1.1 General information

The SVAFO study describes a set of planned decommissioning activities performed at FA facility. However the study should define initial status of FA facility before starting of decommissioning activities – e.g. eventual occurrence of remained operational media and other possible operational liquid or solid radioactive waste, occurrence of other dangerous chemical substances, survey status of constructional and technological barriers. At the same time, the study should specify the final stage after finishing decommissioning works, e.g. green field, grey field or any other usage of FA facility site. In addition, the study does not characterise radioactive waste management activities, such as treatment, conditioning, packaging and disposal.

It would be useful to define a strategy and the end point of decommissioning process for a nuclear facility after its demolition or any other reuse of the site. Common practice is to propose a decommissioning scenario and alternative options.

4.1.2 Input parameters of technological equipment and building structures

The study presents an input database of technological equipment installed in FA facility which includes information on mass, volume, material, dimensions and type of individual technological items. The mentioned database is elaborated in satisfactory extent but radiological data on included technological equipment and their relevant contaminated areas are absent. The area of contaminated equipment and its surface or volume activity and resulting dose rate from the component is necessary for handling of given equipment during the process of decommissioning, namely for cost estimates of decontamination and dismantling.

The database used in the study also does not include building structure items with their characteristic parameters, such as area, mass and surface contamination. A category of technological equipment such as pipe, valves, tanks and a category of building structures such as concrete, steel construction, painting etc. belong to important parameters characterising database items. The SVAFO study comprises only the category of technological items, building structures are not involved in the database. These input parameters have an impact on the choice of dismantling or demolition procedures applied on given technological equipment or building structure.

The study contains a table of room parameters namely room dimensions, room volume, wall, floor and ceiling area. This table contains parameters only for selected rooms in FA facility (see Tab. 3.2-1 in chapter 3.2). Again as in case of input technological database radiological data - average dose rate in individual rooms are missing. All mentioned room parameters are used for evaluation of decommissioning cost, manpower and collective dose equivalent for preparation and finishing activities related to dismantling of either contaminated or non-contaminated equipment and radiological survey of building surfaces in individual rooms. Therefore room dimensions are necessary for all rooms of decommissioned object.

There is a question whether liquid radioactive waste (fuel storage basin water) will be included in decommissioning process of FA facility.

The study summarises amount of materials separately for active and inactive equipment. In order to have an idea for distribution of various materials inside FA facility we would suggest listing of summary table determining amount of stainless, carbon steel or any other material used in contaminated equipment in FA facility, see table Tab. 4.1-1. This table was derived from SVAFO study database of contaminated materials in Appendix 3. The list of contaminated component types with their relevant mass is summarised in Tab. 4.1-2.

Tab. 4.1-1 Summary of contaminated materials from SVAFO database – Appendix 3

Material	**Mass (kg)**
stainless steel	2 336.4
carbon steel	29 137.9
plastic	179.8
electrical cabinets	20.0
porcelain	15.0
Total	**31 689.1**

Tab. 4.1-2 Summary of contaminated components from SVAFO database – Appendix 3

Component	**Mass (kg)**
pipe, valve	1 117.1
tanks	2 780.0
cladding	1 510.0
pump, fan	120.0
ventilation equipment	80.0
heating	100.0
electrical cabinets	20.0
porcelain	15.0
other*	25 897.0
Total	**31 639.1**

** 80% of the handling machines shielded cask is judged to be certifiable as inactive*

In order to compare total material and component balance we had to add new material items representing equivalent components: electrical cabinets and porcelain. Comparison of total material and component balance for contaminated items in both tables does not lead to identical values. The difference is caused by 50 kg carbon steel item from room No.1.09 not included in any relevant component (see pages 10/66 to 12/66 in Appendix 3). Determining amount of stainless steel and carbon steel is only based on designation of listed equipment in the database not mentioned in the SVAFO study material balance. It should be noted that clear separation of stainless steel from carbon steel is very useful for decision of dismantling and decontamination methods applied.

The following presented table Tab. 4.1-3 is a copy of the SVAFO study summary table from chapter 6.2 on amount of Total active components in FA facility.

Tab. 4.1-3 Total active components from chapter 6.2 of the SVAFO study

Item	**Mass (kg)**	**Space occupied (m^3)**
Tanks	2 780	19.60
Sheet cladding	1 510	0.26
Pipes, valves (volume x 1.5)	1 117	3.29
Pipe support (mass x 0.25)	279	0.82
Pumps	120	0.12
Ventilation equipment	80	0.63
Heating system components	100	0.20
Porcelain	15	0.10
Shielded casks + Other	25 897	4.97
Total active components	**31 919**	**30.02**

The comparison of component balance in Tab. 4.1-2 and Tab. 4.1-3 does not lead to total identical values. The difference is caused by mass of pipe supports (279 kg) that is derived from the mass of pipes + valves items (25% from 1 117 kg). However the category of pipe supports is not included in the database in Appendix 3. On the other hand, “electrical cabinet” component included in the database in Appendix 3 is not quantified in Tab. 4.1-3 in total active components balance.

The same material balance summary was derived from Appendix 3 also for non-contaminated materials (see Tab. 4.1-4) and components respectively (see Tab. 4.1-5).

Tab. 4.1-4 Summary of non-contaminated materials from SVAFO database – Appendix 3

Material	Mass (kg)
stainless steel	24,9
carbon steel	50 486,3
copper	213,2
aluminium	653,9
plastic	32,7
thermal insulation	2 103,0
electrical cabinets	2 331,3
cable supports	398,1
cables	103,2
motors	410,0
porcelain	20,0
Total	**56 776,6**

Tab. 4.1-5 Summary of non-contaminated components from SVAFO database – Appendix 3

Component	Mass (kg)
pipe, valve	2 585,9
tanks	1 800,0
pump, fan	815,0
ventilation equipment	3 054,8
heating	1 917,0
thermal insulation	2 103,0
electrical cabinets	2 331,3
cable supports	398,1
cables	103,2
motors	410,0
porcelain	20,0
other	41 100,0
Total	**56 638,3**

In order to compare total material and component balance we had to add new material items representing equivalent components: thermal insulation, electrical cabinets, cable supports, cables, motors and porcelain. Comparison of total material and component balance for non-contaminated items in both tables does not lead to identical values. The difference is caused by the following discrepancies in the Appendix 3 database:

- material item – Stack external insulation 100 mm assigned to aluminium material of 88,3 kg (see pages 58/66 – 60/66 in Appendix 3) is not related to any components
- material item in room No. 1.12 – Handling machine, shielding cask, cable drum, motor assigned to steel material of 100 kg (see pages 61/66 – 63/66 in Appendix 3) is represented by 50 kg of "other" component.

The following presented table is a copy of the SVAFO study summary table from chapter 6.2 on amount of Total active components in FA facility.

Tab. 4.1-6 Total inactive components from chapter 6.2 of the SVAFO study

Item	Mass (kg)	Space occupied (m^3)
Tanks	1 800	11.22
Pumps, compressors	235	0.58
Heating system components	1 917	3.43
Pipes, valves and fittings	2 586	3.06
Pipe support (mass x 0.25)	646	0.76
Electrical cabinets	2 331	11.66
Cable supports	103	0.41
Cabling	398	0.66
Motors	410	0.20
Porcelain	15	0.12
Insulation excluding ventilation	1 478	5.02
Ventilation equipment		
Fans	580	1.09

Item	Mass (kg)	Space occupied (m^3)
Steel ducting	759	1.55
Aluminium ducting	540	2.66
Other ventilation equipment	1 756	8.96
Insulation ducts/stack	624	2.08
Other		
Handling machine	13 050	95.99
Service gantry	3 000	9.00
Travelling crane	25 000	17.00
Total inactive components	**57 234**	**175.44**

Comparing total inactive components from Tab. 4.1-6 with total component balance from database in Appendix 3 in Tab. 4.1-5 there have been identified the following discrepancies:

- Component categories in the database are a bit different from the ones listed in Tab. 4.1-6 that are more itemised especially for "ventilation equipment", "insulation" and "other" components.
- Difference of 50 kg between "other" component items in the database and in summary balance in Tab. 4.1-6.
- "Pipe support" inactive components are not included in the database in Appendix 3 as in case of active components.

For the sake of clarity, material balance for active and inactive components should be listed for each individual equipment category.

In active component balance in Tab. 4.1-3 there is a note for "shielded cask+other" item with the mass of 25 897 kg that 80% of this material is judged to be certifiable as inactive. That means only 5 179 kg of this component item would be necessary to decontaminate. Shifting of 80% of the mentioned active component to inactive group would cause a decrease of total active components from 31 919 kg to 11 201 kg. At the same time inactive components would be increased from originally evaluated 57 234 kg to 77 952 kg. This conclusion would be suitable to note in summary material balance for FA facility.

Input radiological data

Input radiological data are significant even dominant in decommissioning process planning. Radiological situation influences a need of pre-dismantling decontamination, potential use of remote dismantling techniques and use of post-dismantling decontamination or decontamination of building surfaces. It has an effect on amount of needed manpower, collective dose of personnel, distribution and amount of RAW and at overall costs in final. Thus it is important to obtain relevant radiological data as detailed as possible. It means both quantity and quality of data.

In SVAFO study there is some information about radiological situation within FA facility, but it is only very partial and brief.

Contamination

There is a lack of information about contamination of individual items of technological equipment and building surfaces. The only information about estimated pipeworking contamination is presented. Contamination is derived on the basis of conversion factors from dose rates. Information about assumed radionuclide composition of contamination is missing - especially about a presence of alpha contaminants and long lived nuclides (in the case of material on site dumping). The amount of contaminated area of individual building surfaces and technological equipment is very general (only some percents of decontamination basin and fuel storage basin).

Dose rates

Information about assumed dose rates in individual rooms within FA facility is missing. There is only general information about dose rates of pipeworking. Interval of dose rates varies in the wide range from 0.01 up to 2 mSv/h.

It would be very useful to obtain more detailed and qualified radiological data about individual technological equipment and building surfaces items of FA facility. Data on level of contamination, radionuclide composition, size of contaminated area and resulting dose rate of given item are significant in decision of eventual pre-dismantling decontamination usage. It influences also using of post-dismantling decontamination in effort to maximize amount of materials with final contamination under the clearance

levels. Also assumption of collective dose equivalent connected with labour content and dose rates is very important from the point of view of personnel radiation safety.
If it is difficult to obtain information about contamination of individual equipment or building surface items, it would be useful to find out an assumed range of contamination and dose rate levels at least. Similar approach can be used in case of room dose rates.

DECOMMISSIONING PROCEDURES

Although the SVAFO study mentions a need of radiological survey, the scope and methods of radiological survey are not specified. The SVAFO study states the necessity of pre-dismantling decontamination application for active components of FA facility. However relevant equipment necessary to decontaminate as based on results of radiological survey are not identified. In addition, the study does not mention post-dismantling decontamination application, which has a direct impact on distribution of materials destined to repository and released into environment.

In chapter 5.1 of the study, the list of sequential considered decommissioning activities for FA facility is given although selected methods for individual activities are not specified. Namely the methods of pre-dismantling decontamination, dismantling and demolition procedures together with specified necessary equipment. As well as radioactive waste (RAW) treatment, conditioning, packaging technologies and disposal are missing. Especially characteristic data describing RAW management such as monitoring, sorting, segmentation, treatment, conditioning, packaging, transport to storage facility or disposal in repository. The study assumes to release as much material as possible into environment or alternatively transport RAW from decommissioning with higher degree of contamination to repository for short-lived materials (SFR-3).

In context of building structures decommissioning, a mechanical decontamination of contaminated building surfaces is taken into consideration in the study. Released materials from demolition are considered to be primarily used for back-filling of underground volume below -0.5 m level. However the selected -0.5 m level is not justified.

UNIT FACTORS FOR DECOMMISSIONING PROCEDURES

Each decontamination, dismantling or demolition procedure is characterised by a set of specific unit parameters, such as specific energy or media consumptions, specific costs for relevant equipment procurement and their consumption during decommissioning procedure, specific manpower etc. These parameters are mostly given per unit mass of dismantled material or per unit area of decontaminated material and are not included in the study.

On the other hand, the SVAFO study contains specific manpower for dismantling of various technological equipment categories given in mass per manhour. Appendix 4 of the study comprises manpower needed for dismantling of individual active and inactive components. Specific costs of 450 SEK/h for dismantling activities is considered in the study. In addition unit manpower of 21 manhour/room is assumed for dismantling preparation activities. Taken into account practical experience, specific manpower for dismantling is decreasing with an equipment size (the bigger valve, pump or pipe the less unit manpower per mass is needed). However, in case of decommissioning of intermediate spent fuel storage facility with smaller variety of installed equipment mentioned unit parameters used in SVAFO study are satisfactory.

For the purpose of demolition procedures, there are in Appendix 6 of the study listed basic dimensions of selected rooms, building surface areas, relevant room volumes and total amount of concrete, steel and rebar for active and inactive demolition debris. Appendix 7 of the study provides data on mechanical decontamination of building surfaces: depth of removal (5 cm) and volume of removed concrete material.

Appendix 8 summarises amount of building structures – room fittings (concrete, rebar, steel) necessary to demolish below -0.5 m level before backfilling. Appendix 9 summarises amount of above-ground building structures to be demolished. Demolition activities are not characterised by their typical specific unit parameters (specific energy, media, equipment consumption, specific costs and manpower per each building structure category).

4.2 DISCUSSION ON SVAFO COST ESTIMATES METHODOLOGY

The costing methodology applied in SVAFO study is relevant for the preliminary first-stage calculations of decommissioning parameters and also the structure and extent of input data correspond to the costing methodology adopted. For applications in the frame of more detailed calculations of decommissioning parameters and for the planning of decommissioning it would be useful to enhance the costing methodology and in relevant manner also the input database.

It is expected that the aim of decommissioning planning in next phases would be to develop a package of data for decommissioning which will include:

- work breakdown structure
- time schedule for the work breakdown structure
- tables of calculated data corresponding to the work breakdown structure
- tables of costs and other calculated decommissioning data in the standardised structure according to the document "A Proposed Standardised List of Costs Items for Decommissioning Purposes" (PSL) [PSL] , which defines the structure of decommissioning activities for which the decommissioning costs are to be presented.
- parameters of personnel needed for performing the decommissioning activities
- material balance with the interim and final material items
- equipment needed for performing the decommissioning activities
- time graphs for selected calculated parameters.

This list of data for decommissioning requires also an application of relevant costing methodology. It is needed to underline the fact that one of the most important trends in decommissioning costing is aimed to use the standardised cost structure [3] in wide extent. The costing methodology should implement also this standardised structure.

General requirements for decommissioning costs estimation methods which are based on cost unit factors approach, have typical following main steps [4]:

1) Definition of cost categories which include the:

- Activity-dependent costs, related to the extent of "hands-on" work like dismantling
- Period-dependent costs, proportional to duration of individual activities/phases
- Collateral costs and costs for special items which can neither be assigned to hands-on work activity nor to period-dependent activity
- This general procedure was applied in the SVAFO study and should be further developed in more detailed structure. For the case of activity-dependent cost should be applied in accordance with more detailed categorisation of inventory technology and building structure items with relevant extent of technologies needed for performing decommissioning activities lik dismantling, decontamination, decontamination, etc. For the case of period-dependent activities should be applied more detailed definition of working groups and working conditions. As for the collateral costs, the extended definition should be applied in order to distinguish between the investment costs and expenses and the proper allocation of the collateral costs in the frame of the standardised structure should be defined.

2) Identification of decommissioning activities and inventories with two main phases:

- Identification of discrete elementary activities for which unit factors are defined
- Completion of the list of activities with a plant buildings/equipment inventory in order to define the extent of activities.

The first item represents the definition of the extent of decommissioning activities for the decommissioning project in the standardised structure according [3]. The second point means extension of the structure of decommissioning activities according the structure building objects – floors - rooms, it means the definition of full structure of decommissioning activities which are repetitive for each room according the content of the inventory database. Because the general structure of hands-on decommissioning activities is room oriented, sets of preparatory and of finishing activities should be defined on the level of the rooms for each group of decommissioning activities like dismantling or decontamination and radiation monitoring of building surfaces. In this way the full inventory of decommissioning activities can be defined.

3) Definition of unit factors and conditions for calculations

Unit factors are defined in accordance to the details of the items considered in the plant inventory and in the decommissioning activities listing. Unit factors are defined for ideal working conditions and correction factors are defined that reflect the specific working conditions (radiation, working height, etc.). Calculation procedures for the individual calculation items should be defined in the standardised calculation structure as as one default procedure and set of supplement calculation procedures for editing by the user. The remote controlled / manual procedures should be defined based on actualised radiological inventory data and acceptance limits for manual work. The correction factors (work in radiation fields, on scaffolding) should be calculated based on inventory radiological data. The local input data entry points (e.g. working group parameters / duration of period dependent activities, fixed costs, contingency, etc.) should be defined as default values or empty data entry points for user entering or editing the input calculation data. According to the cost structure of the decommissioning costs, a contingency should be defined for each calculation item which reflects the level of uncertainty in the estimates.

4) Project scheduling

The work breakdown structure should be defined based on local conditions and on interactions with other decommissioning projects. For individual items of the work breakdown structure should be allocated the relevant items from the standardised calculation structure by grouping of the calculation items or by direct one-to-one linking of items form both structures. In this way can be achieved that the decommissioning data can be calculated in the standardised structure and the work breakdown structure specific for the decommissioning project can be defined. Project time schedule is the constructed by mutual aligning of the items of the work breakdown structure based on calculated duration of individual hands-on work phases and based on the plant inventory data, resulting in identification of critical path for decommissioning project. The duration of period-dependent activities can be then adapted to the individual calculated duration of hands-on decommissioning activities or phases.

5) Collateral Costs and Costs for Special Items

Definition of collateral costs and costs for special items, like cost for heavy equipment for site support, health physics equipment and supplies, licenses and permits, costs for lighting, heating, cooling, income from sold equipment or scrap, etc. As for already defined the collateral costs should be defined as investment costs or expenses and the proper allocation in the frame of the standardised structure should be defined.

Except of the standardisation of decommissioning calculation which is implemented in the above consideration, other aspects are recommended to be taken into account for more accurate calculation of decommissioning parameters and for defining the time schedule of the decommissioning projects:

- Algorithmization of material and radiological aspects of decommissioning which represents the linking of calculation process for modelling the material and radioactivity flow in decommissioning based on real decommissioning infrastructure. This enables the on-line optimisation of the decommissioning activities and waste management processes. Impact of character and level of radioactivity on decommissioning is significant and determines the choice of decommissioning activities (manual/remote, etc.), the amount and parameters of waste, its processing and disposal and modifies significantly the decommissioning costs, exposure, manpower and other decommissioning parameters.
- On-line optimisation - optimisation of the work breakdown structures of decommissioning options in standard project management software with direct calculation link to calculation structures.
- Multi-option work - definition, calculation and evaluation of a set calculation options which cover all decommissioning scenarios considered
- Sensitivity analysis for decommissioning - supporting methodology for revealing the possible margins and trends of costs and other decommissioning parameters by varying selected input parameters like contamination, nuclide composition, start dates, etc.

As for the calculated parameters it is recommended that the costing methodology produce following set of decommissioning parameters:

- general decommissioning parameters - costs, manpower, exposure, duration, number of workers, consumption items.
- material parameters - parameters of output materials (weight, inner/outer surface, volume) including all interim waste forms, final waste form, released materials, gaseous and liquid effluents
- nuclide parameters - radioactivity of output material items evaluated for individual radio-nuclides linked to each material item
- profession resolved parameters - manpower / exposure items resolved for individual professions of the working group
- time parameters - start, duration of individual decommissioning activities
- equipment – equipment/instruments for performing of decommissioning activities

The formats of the data should be following:

- Summary format with user selected general calculated decommissioning parameters - costs, manpower, exposure, duration, number of workers, consumption items, etc.
- Standardised PSL formats - table of user selected calculated parameters assembled in standardised format of PSL
- Time graphs - time graphs with pre-selected time scale for any user selected calculated parameter
- Gantt chart - decommissioning Gantt charts in the standard software for project planning with user selected resource parameters from the list of calculated parameters

4.3 SVAFO OUTPUT PARAMETERS DISCUSSION

Costs and manpower

SVAFO study output parameters were described in chapter 3.4. “Results from SVAFO cost estimates for FA facility”. Output parameters from SVAFO study (decommissioning costs and manpower) are divided into three categories: In the first category - Preparatory work on-site prior to demolition are presented decommissioning costs together with particular manpower needs. In the second - Preparatory, supporting and concluding efforts and third - Actual demolition work category only decommissioning costs are evaluated. Manpower of dismantling activities for active and inactive components is given in separate table in Appendix 4. Described structure of output parameters used in SVAFO study is not suitable from the point of view of decommissioning cost and manpower identification for each individual decommissioning activity.

Mentioned shortcomings could be solved by output parameter structure according to standardised decommissioning cost items list, so called PSL structure (Proposed Standardized List of Items for Costing Purposes in Decommissioning) that was elaborated and recommended by European Commission, OECD/NEA (Organization for Economic and Cooperation Development/Nuclear Energy Agency) and IAEA (International Atomic Energy Agency) [3]. PSL structure represents a systematised structure of decommissioning activities and it is extended into three numbered levels. First level layout is as follows:

01 Pre-decommissioning actions
02 Facility shutdown activities
03 Procurement of general equipment and material
04 Dismantling activities
05 Waste processing and disposal
06 Site security, surveillance and maintenance
07 Site restoration, cleanup and landscaping
08 Project management, engineering and site support
09 Research and development
10 Fuel and nuclear material
11 Other costs

Each level ranges decommissioning activities or groups of decommissioning activities that are identical or very similar. Although PSL structure was primary assigned for systemisation of cost items it is used for also for systemisation of other decommissioning parameters. Some decommissioning activities (e.g. pre-dismantling decontamination, dismantling, radiological control of room, etc.) must be structured in more detail up to the lowest level of PSL structure (room level or equipment level respectively). Therefore standard PSL structure (static level which is common for all of nuclear facilities) is developed for some activities according to structure: object – floor – room – equipment of given nuclear facility. Hereby it is formed a dynamic PSL structure that is unique for each of nuclear facility.

Amount of waste and collective dose equivalent

The study lists three eventual outputs for waste from decommissioning of FA facility:

- release for free disposal
- transport to a safe depository for short-lived material
- transport to a safe depository for long-lived material.

However it does not mention criteria for material sorting among these groups - levels of radioactivity, radionuclide composition respectively. There are reported only summary mass and volume of materials destined to:

- storage for short-lived wastes (SFR)
- backfilling below ground level
- dump for conventional wastes.

For particular values, see Tab. 3.4-5 in chapter 3.4.3. Given table does not allow identifying individual type of materials (amount of steel, non-ferrous metals and other non-metal materials) destined to particular waste streams. In addition, there is not mentioned assumed amount of releasable material after application of post-dismantling or pre-dismantling decontamination respectively. The study states that the presence of long – lived radionuclides is judged to be negligible but this statement is not substantiated by any data or reference.

Relevant table containing amounts of waste divided as mentioned above is situated as far as at the end of document and not in appropriate chapter 5.1.2 in the study.

There is a division of liquid wastes into 3 categories listed in Appendix 12 :

- medium active waste not to exceed 40 GBq/m^3
- low active waste not to exceed 400 MBq/m^3
- process water not to exceed 400 Bq/m^3

However there is not mentioned which categories of liquid RAW are assumed to occur (especially in the case of pre- and post-dismantling decontamination) and their amount.

The study further does not report radiological impact on personnel performing decommissioning activities - Collective dose equivalent (CDE). CDE belongs among the basic output decommissioning parameters and together with decommissioning costs and manpower influencing upon choice of optimal decommissioning option. Therefore it is not possible to estimate radiation safety during carrying out of individual decommissioning activities especially pre-dismantling decontamination, active dismantling, post-dismantling decontamination and decontamination of building surfaces. Subsequently it is hard to propose eventual arrangements for critical activities or minimize radiological impact on personnel according to ALARA principles. For mentioned reasons it would be necessary to complete CDE to output parameters for each decommissioning activity.

Possibilities of improvement and enhancement of decommissioning parameters estimated for FA facility can be found in using advanced costing methodology. One of necessary condition for this methodology application is completing and structuring of input and output data as described in chapters below.

5. CONCLUSIONS FROM THE ANALYSIS OF THE SVAFO STUDY FOR FA FACILITY IN STUDSVIK

Within the previous chapters 3 and 4, the analysis of the SVAFO study [1] has been performed together with recommended proposals for an upgrade of future decommissioning study for FA facility in Studsvik. In order to perform the complex analysis of SVAFO study on decommissioning cost estimates, the input inventory database of FA facility (available as an Appendix 3, 6, 7 of the SVAFO study) was evaluated and compared with the text part of the given study.

The main results of the SVAFO study analysis for FA facility in Studsvik and proposed solutions for upgrading the study in order to achieve more precise results of calculated decommissioning parameters are as follows:

1. As for the input data used in the SVAFO study we would suggest defining more clearly the strategy and the end point of decommissioning process for FA facility after its demolition (e.g. green, grey field or any other reuse of the site) and propose and evaluate a decommissioning scenario with alternative options. Further on, it would be useful to characterise planned FA facility decommissioning process (scope, methods and techniques) and especially the radioactive waste management activities, such as treatment, conditioning, storing and disposal. A comprehensive calculation database should be developed containing the calculation data for all processes involved in decommissioning.
2. The SVAFO study input technological database is of satisfactory extent as for the information on quantity, equipment category, mass, material dimensions, volume etc. Additional work is needed to fit the technology inventory database in full compliance with future use of the advanced costing methodologies. However, the inventory database should be completed by building structure items (walls, steel constructions etc.) with their particular parameters, such as area, material, mass and surface contamination, quality of surfaces and other data having an impact on the choice of decommissioning technique.
3. It is necessary to include absent radiological data for input inventory database items, especially missing information on particular area of contaminated equipment, its surface or volume activity with radio-nuclide composition and the resulting dose rate from the component. This would enhance the quality of the calculated decommissioning parameters, especially in the evaluation of the material and radioactivity flow within the decommissioning process.
4. In addition, the inventory database of FA facility should be completed by data for all rooms, like dimensions, relevance for controlled area, average dose rate and other data affecting the calculated parameters (costs, manpower, CDE) for dismantling preparation and finishing activities.
5. Although the SVAFO cost estimates methodology is relevant for the preliminary first-stage calculations of decommissioning parameters, it would be useful to enhance the costing methodology using standardised structure of calculated costs and other decommissioning parameters – a so called PSL structure in document [3]. This would facilitate the presentation and comparison of results of the decommissioning project on the international level.
6. In order to achieve more transparent calculated decommissioning parameters for FA facility it would be necessary to report decommissioning costs, manpower, collective dose equivalent for the personnel (CDE representing transparent calculated radiological impact) and other decommissioning parameters for each individual decommissioning activity performed. Planning and evaluating of the performed decommissioning activities would be then more efficient.
7. Reporting individual waste streams of solid and liquid radioactive waste destined either to repositories or released into environment would help in better identification of materials arisen from FA facility decommissioning process and would contribute to environmental impact assessment.

The summarised conclusions from the SVAFO study analysis above are fully in compliance with recommendations which have been given in other SKI financed research projects, e.g. for FA facility documented in [5] but also for another storage facility at Studsvik site documented in [6].

The above mentioned conclusions of the SVAFO study analysis are the prerequisites for implementation of advanced costing methodology, particularly using OMEGA code calculations that are both characterised in the following chapters.

6. REVIEW OF THE ADVANCED COSTING METHODOLOGY

6.1 REVIEW OF COSTING METHODOLOGIES

Decommissioning of nuclear facilities is in general a complex and expensive process of technical and non-technical activities covering the time scale of tens of years. Estimating of parameters of decommissioning is one of the main issues in preparatory phases of decommissioning. The main aim of these activities is to prepare files of qualified data like costs, exposure, manpower, personnel / equipment needed, amounts of waste, time schedules, time graphs etc. Based on this qualified data, the decommissioning process can be planned to be accomplished.

- safely - with minimal actual and future influence on personnel/environment
- economically - according to costs / resources optimized decommissioning option
- in due time - according to optimised decommissioning time schedule.

The decommissioning costs should be known already in early stages before starting decommissioning and in the case of new nuclear facilities at the commissioning stage. The accuracy of costs estimates should be as best as possible in total, in its fine structure and in time structure in order to raise-up the relevant decommissioning fund.

Current costing methodologies were developed based on experience from decommissioning of nuclear facilities with standard shutdown properties. The methodologies could then be used for cost estimates for similar facilities. The unit factors, calculations formulas and other elements of cost methodologies could be applied after comparison of facilities and relevant corrections for the differences in size, inventory, local factors and other aspects. The quality of results depends on proper adjustment of the methodology for facility conditions.

One of the general aspects of these traditional methodologies is the fact that the cost structures are in general different for various projects. The cost structure of the projects is then less comparable and also less transparent. When applying the above discussed cost estimating methodologies for a nuclear installation which is not typical or different from similar standard nuclear installation for example in radiological situation (accident during operation), the errors in final costs can arise.

Decommissioning costs estimation methods, identified in major decommissioning projects are based on cost unit factors approach with following main steps [4]:

1) Definition of Cost Categories
   - Activity-dependent costs, related to the extent of “hands-on” work like dismantling
   - Period-dependent costs, proportional to duration of individual activities/phases
   - Collateral costs and costs for special items which can neither be assigned to hands-on work activity nor to period-dependent activity
2) Identification of Decommissioning Activities and Inventories
   - Identification of discrete elementary activities for which unit factors are defined
   - Completion of the list of activities with a plant buildings/equipment inventory in order to define the extent of activities.
3) Definition of Unit Factors
   - Unit factors are defined in accordance to the details of the items considered in the plant inventory and in the decommissioning activities listing
   - Unit factors are defined for ideal working conditions and correction factors are defined that reflect the specific working conditions (radiation, working height, etc.)
4) Project Scheduling and Staff Requirements
   - Project time schedule construction based on calculated duration of individual hands-on work phases and based on the plant inventory data.
   - Identification of critical path for decommissioning activities.
   - Calculated duration of decommissioning activities / phases are used as a basis for definition of duration of period-dependent activities for which the staff is defined.
5) Collateral Costs and Costs for Special Items

- Definition of collateral costs and costs for special items, like cost for heavy equipment for site support, health physics equipment and supplies, licenses and permits, costs for lighting, heating, cooling, income from sold equipment or scrap, etc

6) Total costs definition
   - Total costs estimate are obtained as a sum of the costs three categories: activity-dependent costs, period-dependent costs, collateral costs
   - The cost estimates may be adjusted to include a contingency that reflects the level of uncertainty in the estimates.
   - A general contingency expressed in some special cost items may be applied to the total cost estimate.

6.2 ADVANCED DECOMMISSIONING COSTING

Based on experience and general trends in decommissioning costing, the traditional costing methodologies were enhanced at DECOM to an advanced generic decommissioning costing methodology which eliminates the discussed disadvantages of traditional methodologies and refers to following main issues:

1) **Standardisation:** Implementation of standardised cost structure for decommissioning
2) Algorithmization of **material and radiological aspects** of decommissioning: Linking of calculation process for modelling the material and radioactivity flow in decommissioning based on real decommissioning infrastructure for enabling the on-line optimisation of the decommissioning activities and waste management processes.
3) **On-line optimisation** and multi-option work: Definition, calculation and evaluation of a set calculation options which cover all decommissioning scenarios considered
4) **Sensitivity analysis** for decommissioning: Supporting methodology for revealing the possible margins and trends of costs and other decommissioning parameters by varying selected input parameters like contamination, nuclide composition, start dates, etc.

STANDARDISATION ASPECTS

As it was already mentioned in chapter 4.3, OECD/NEA, IAEA and EU issued in 1999 the document "A Proposed Standardised List of Costs Items for Decommissioning Purposes" (PSL), which defines the structure of decommissioning activities for which the costs are to be presented. PSL document [3] defines standardised cost structure for decommissioning activities ranging from pre-dismantling decontamination through dismantling up to decommissioning waste management activities including supporting and planning activities.

The reason for issuing the document were inconsistencies in presented costs of various decommissioning projects caused by different extent of activities, technical / local / financial factors, waste management systems, etc. The main purpose of the document is:

- To facilitate communication
- To promote uniformity
- To encourage common usage
- To avoid inconsistency or contradiction of results of costs evaluations
- To be of world wide interests to all decommissioners.

The principles of standardised list of decommissioning cost items were fully implemented into the costing methodology of DECOM Slovakia. Standardisation of other aspects like fine costs structure, structure of inventory data, etc. are under consideration for extended standardisation.

MATERIAL AND RADIOLOGICAL ASPECTS

Character and level of radioactivity can have in general an essential influence on choice of decommissioning activities (manual/remote, etc.), on amount of waste and its processing, on demand of volume in repositories, etc. and finally on decommissioning costs, exposure, manpower and other decommissioning parameters. These impacts are especially important in the case of a facility with non-standard radiological situation, for example after an accident.

Material and radiological aspects in advanced decommissioning costing refer to following issues:

- Algorithmization of the entire material flow in decommissioning by calculation modelling in order to on-line optimise the decommissioning and waste management
- Algorithmization of radiological aspects in order to manage the flow of radioactivity linked to the material flow and to manage the effect of time in decommissioning (to implement the impacts of radioactive decay).

These principles enable to increase the accuracy of calculation of decommissioning parameters related to material flow in decommissioning, to optimise the waste management and to perform the sensitivity analysis.

ON-LINE OPTIMIZATION, MULTI-OPTION WORK

On-line optimization represents the work with the Gantt chart of the decommissioning option in the standard MS Project software. The on-line data link between the standardised calculation structure and the Gantt chart in MS Project enables the recalculation of decommissioning parameters with optimised starting dates of individual decommissioning activities (to include the effect of radioactivity decay).

The developed advanced costing methodology has multiple options character it means that a set of decommissioning options is defined for a decommissioning project in order to evaluate all possible scenarios of decommissioning in the frame of the project. Each decommissioning option is calculated, optimised and evaluated individually and the option optimal for the project is selected based on multi-attribute analysis.

CONCEPT OF SENSITIVITY ANALYSIS

Additional aspects of the advanced costing methodology due to internal linking of the calculation process is the possibility to perform the sensitivity analysis which can reveal the hypothetical margins and trends of decommissioning costs and other decommissioning parameters by varying for example the levels of contamination, nuclide composition of the contamination (effects of alpha-contaminants), by application of various decommissioning technologies (application of pre-dismantling decontamination, various scenarios of RAW management – post-dismantling decontamination, melting available) or by varying the durations of deferred decommissioning phases, etc. Complex graphs, tables, time scans, etc., can be developed for supporting the decision making processes.

The concept of sensitivity analysis enables to analyse the impact of various input parameters on final parameters of decommissioning projects by:

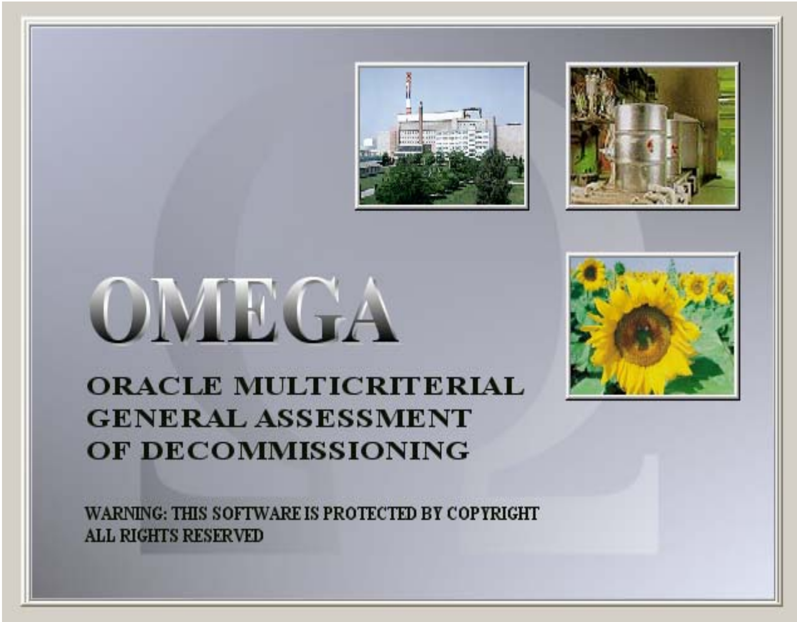
- Varying the input amounts of individual waste items
- Definition of date parameters for waste streams
- Varying the radiological parameters of waste items – volume radioactivity, nuclide composition
- Varying the parameters of individual processes (unit factors, working groups, secondary waste generation, etc.
- Definition of auxiliary activities, fixed costs for processes, costs for equipments, etc.
- Waste management project structure optimisation using the Gantt chart o the project.

6.3 COST CALCULATION CODE OMEGA

The computer code Omega developed at DECOM Slovakia fully integrates the above mentioned features of advanced decommissioning costing methodologies. OMEGA code is the generic planning tool for applications in decommissioning decision making processes for nuclear facilities of various types and radiological properties with following purposes [7]:

- Definition of the set of decommissioning calculation options for facilities with various building and technology inventory structure and with various radiological parameters
- Calculation of costs and other parameters of decommissioning (such as manpower needs, collective dose equivalent, waste distribution from decommissioning process etc.) for individual calculation options, for calculated data processing and evaluation
- Optimisation of individual calculation options and waste management within the individual options
- Comparison of decommissioning options and selection of the most suitable one based on multi-attribute analysis

Fig. 6.1 Introductory window of the OMEGA code



Basic properties of the calculation code OMEGA for applications on the level of the calculation options:

- Activity based costing was implemented based on the Proposed Standardised List of Costs Items (PSL) which enables to use the code for various types of nuclear facilities.
- Automatic generation of the standardised calculation structure based on template calculation structures, conditions defined by the user and based on inventory data. Structures with approx. 60 000 items were generated and used. This automatic generation of the calculation options facilitates significantly the multi option work.
- The code was developed for Jaslovske Bohunice A-1 NPP costing with complicated radiological situation. A new concept of calculation modelling of material and radioactivity flow control was implemented in order to increase the accuracy of calculation and for optimisation of RW management. The code can be used for facilities with various radiological states. The accuracy of calculation of decommissioning parameters is significantly higher then using the traditional costing methodologies where the amounts of waste are estimated.
- The calculation process is nuclide-resolved. This enables the use of limits on the nuclide level for treatment / conditioning / disposal / release (unconditional and conditional) of materials as well as calculation of the radioactivity decay to study the effect of deferred activities.
- On-line optimisation of decommissioning options in standard Microsoft Project software using the work breakdown structure, constructed as the upper layer over the standardised structure.

For achieving the above discussed properties, following principles of algoritmisation of costs calculation in Omega are applied:

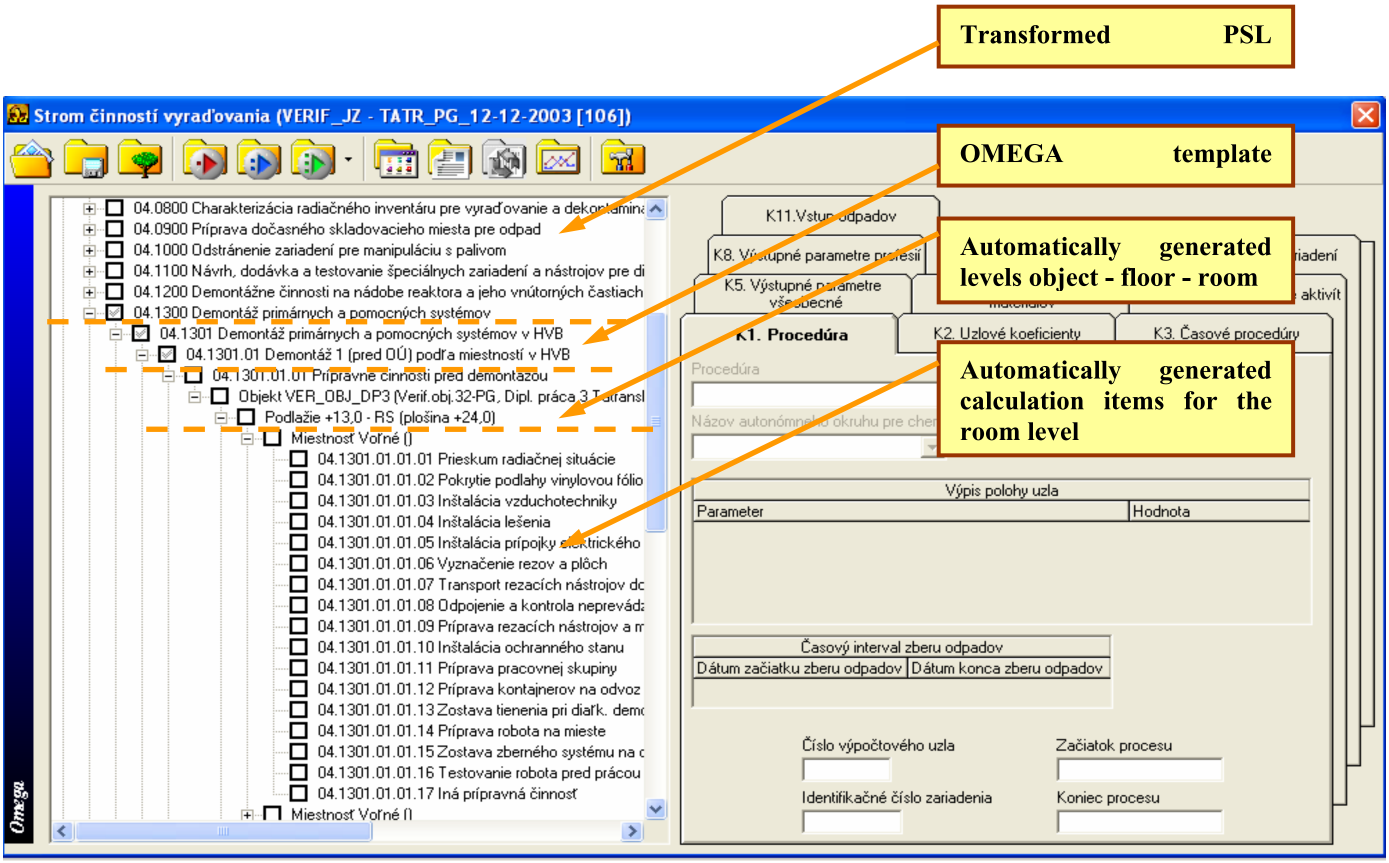
1) What to do - management of the standardised calculation structure. Definition of decommissioning activities and extent of calculation
2) How to do - management of calculation conditions. Definition of calculation procedures, definition of local calculation input data and correction factors
3) In what sequence - management of material / radioactivity flow in decommissioning by definition of calculation sequence and by data linking of calculation procedures (calculation modelling of decommissioning process)
4) At what time - management of time in decommissioning by on-line optimisation of decommissioning time schedule with feed-back to the calculation structure supported by dynamical recovery of radiological parameters

1) DEFINITION OF DECOMMISSIONING ACTIVITIES/EXTENT OF OPTION

The tools for implementation of the Proposed Standardised List of Costs Items (PSL) were developed in following levels displayed on Fig. 6.2:

- The standardised PSL structure – defined decommissioning activities by specific numbers in accordance with PSL document [3]
- Omega template PSL structures - extended PSL structure with lower numbered levels were developed for decommissioning activities and for waste management
- Option specific PSL calculation structure - user defined specific PSL structure based on a selected template structure. At lowest levels, where applicable, modes for automatic generating of lower calculation levels are defined, e.g. object - floor - room - equipment structure
- Executive PSL calculation structure (dynamic PSL structure) - generated based on static PSL structure and facility inventory data. General structure: Building objects - floor - room - inventory item. Extent of calculation is defined by the user by switching decommissioning activities in generated dynamic PSL structure

Fig. 6.2 Example of standardised calculation structure in OMEGA code



2) DEFINITION OF CALCULATION PROCEDURES AND CONDITIONS

Automatic allocation of calculation procedures, generation of default calculation data and user friendly tools for calculation data editing / entry were developed. Calculation procedures for the individual calculation items or formulas for generation of the calculation procedures are pre-defined in the PSL calculation templates. The executive calculation procedures are allocated automatically during the generation of the executive PSL calculation structure as one default procedure and set of supplement calculation procedures for editing by the user.

The remote controlled / manual procedures are selected automatically based on actualised radiological inventory data and acceptance limits for manual work. The correction factors (work in radiation fields, on scaffolding) are calculated during generation of the executive calculation PSL structure based on inventory data and can be edited by the user.

The local input data entry points (e.g. working group parameters / duration of period dependent activities, fixed costs, contingency, etc.) are generated as default values or empty data entry points during generation of the executive calculation PSL structure. The user can enter or edit the input calculation data. The automatic generation of input data entry point together with the generation of default data facilitates and speed up the work with decommissioning calculation options.

3) DEFINITION OF MATERIAL / RADIOACTIVITY FLOW IN DECOMMISSIONING

The concept of material / radioactivity flow control in decommissioning developed at DECOM Slovakia represent an original generic methodology and tools implemented into the standardised OMEGA code for on-line optimisation of decommissioning and waste management processes. The modelling of the processes is based on mathematical material partitioning of inventory items into one-material elements which enter into the pre-defined sequence of calculation / sorting procedures linked each other by unambiguous material links. To each one-material calculation element are linked radiological parameters which are generated during the material partitioning. The generation is based on the calculation category of the inventory items and distribution coefficients relevant for the item category

The concept of nuclide vectors is used for definition of radiological parameters of inventory items (normalised participation of individual radio-nuclides on radiological inventory data). The linked radiological parameters are during the calculation dynamically recovered to the start dates of individual decommissioning activities. The decay of radioactivity of individual radio-nuclides is respected through the entire decommissioning process.

The calculation procedures implement the parameters of individual processes of the decommissioning infrastructure (actually available or planned) for the decommissioning project. In addition to calculation procedures, such as: dismantling, decontamination, demolitions etc, there is a special group of sorting procedures distributing particular materials into specific waste streams. Sorting procedures implement the limits for releasing of materials, acceptance limits for disposal of materials, acceptance limits for individual process (if they are defined) and parameters of individual processes which affect the material / radiological parameters of evaluated items.

Both types of procedures (calculation and sorting) can be linked to pre-defined scenarios of waste management for decommissioning starting from pre-dismantling decontamination up the release of materials or disposal of materials on the surface repository or deep geological repository. Keyboard data entry of waste items for general application in waste management modelling and optimisation is feasible. The waste streams are finally optimised in standard Microsoft Project software.

4) MANAGEMENT OF TIME IN DECOMMISSIONING

The new concept of decommissioning time schedule in the form of the Gant chart in Microsoft Project with bi-dimensional data link (starting date of decommissioning activity and its duration) to the calculation structure enables the on-line optimisation of the decommissioning time schedule. This concept implements directly the impact of time on radiologically dependent decommissioning parameters.

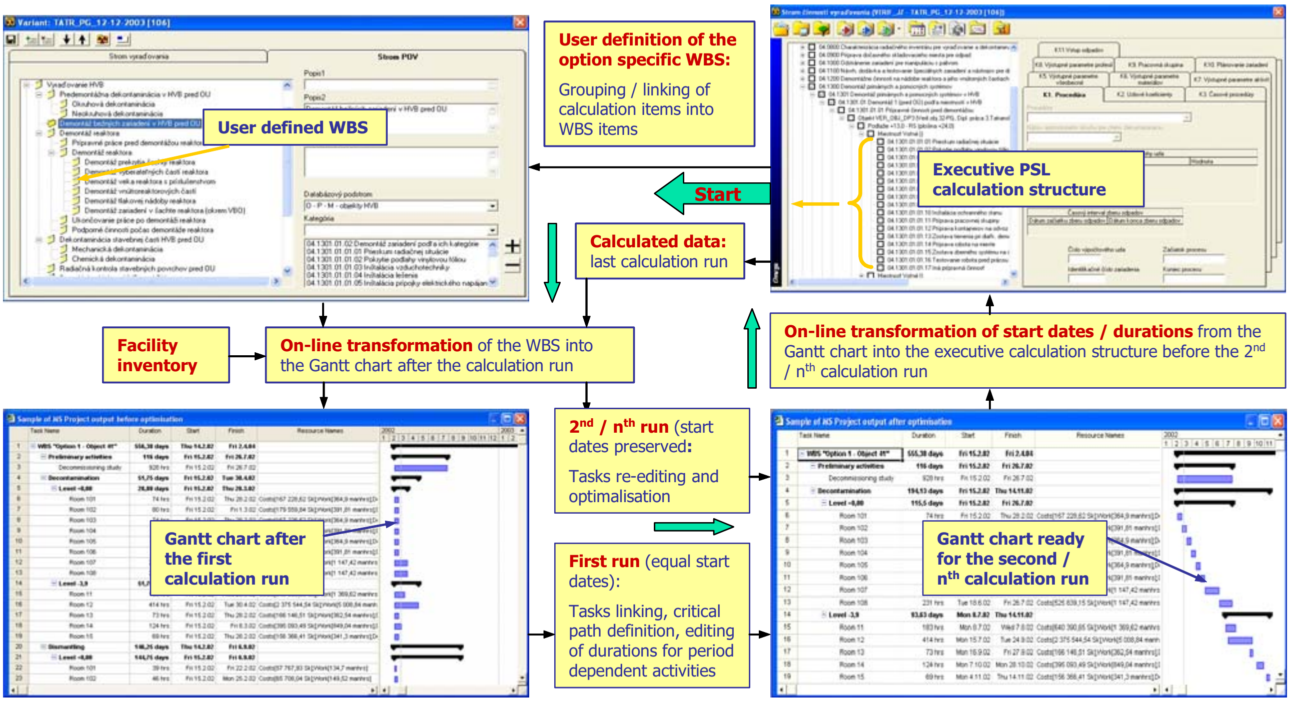
The real sequence and structure of activities in the work breakdown structure (WBS) of a decommissioning project is specific and different from the PSL structure. The WBS in Omega can be defined individually for each calculation option by tools for specific grouping and linking of items of the standardised calculation structure into the items of the WBS. The developed tools enable to transform the WBS, defined in OMEGA code by the user, into the Gantt chart in the standard Microsoft Project software and to generate the user defined resources data for the Gantt chart. The grouping mode (1 : N) of calculation items into the WBS item preserves the total duration of grouped calculation items. The linking mode (1:1) in definition of the WBS represents one to one linking of one calculation item to one WBS item. This mode is used for tasks where the duration is individually optimised in the Gantt chart. The Gant chart is generated automatically by an interface using the work breakdown structure and the inventory database.

The Gantt chart can be optimised using the standard tools of the Microsoft Project. The optimisation represents the linking of activities with calculated durations (activity dependent types of tasks, like dismantling) in order to define the critical path for the option, adjustment of duration of period dependent activities and modifying the optimisation parameters (number of working groups or shifts) where needed. The optimised Gantt chart is used for transfer of start dates and durations back to the executive calculation structure. The start dates for the grouped items are sequenced for individual de-grouped items, for linked items are transferred directly. The duration is transferred for items defined in the calculation structure, see Fig. 6.3.

Start dates of individual calculation items, derived from the Gant chart of the calculation option, determines the actual values of radiological parameters involved in the calculation item. There are two basic modes of calculation run in Omega displayed on Fig. 6.3:

- First calculation run - all calculation items starts with the same date. This mode is used for the first generating the Gantt chart before its optimisation in Microsoft Project.
- Second / nth calculation run - the start dates are derived from the optimised Gantt chart. Effects of time decay (e.g. in deferred dismantling) can then be evaluated directly.

Fig. 6.3 Principal scheme of work breakdown structure (WBS) definition, its transformation into the Gantt chart, optimisation of the Gantt chart and modes of calculation runs



APPLICATION OF ON-LINE OPTIMISATION IN DECOMMISSIONING WASTE MANAGEMENT

Special task in optimisation of the Gantt chart of the decommissioning option is the optimisation of decommissioning waste management. The implemented tools enable to create a multi-stream waste management system which can cover several periods of waste management linked to individual decommissioning phases.

The waste streams are pre-defined in the form of waste scenarios. The user can include the selected scenario into the calculation option. Scenarios with combinations of post-dismantling decontamination or melting facility available at the site.

The amount of wastes entering the individual streams is the result of calculation in relevant waste generating calculation items like dismantling, decontamination (wet and dry), demolition and this on-line data link increase the accuracy of calculation of the parameters for the waste management. The secondary waste items are calculated based on distribution coefficients

Keyboard data entry of waste items is feasible for calculating the parameters for management of operational waste (not the result of previous calculation).

The range of on-line waste management include all waste handling activities from the origin of the waste (or the keyboard entry) up to the release of materials or disposal of conditioned waste at surface or geological repository.

Based on described features of OMEGA code decommissioning calculation a simplified scheme of OMEGA data processing can be created:

Fig. 6.4 Simplified scheme of OMEGA data processing

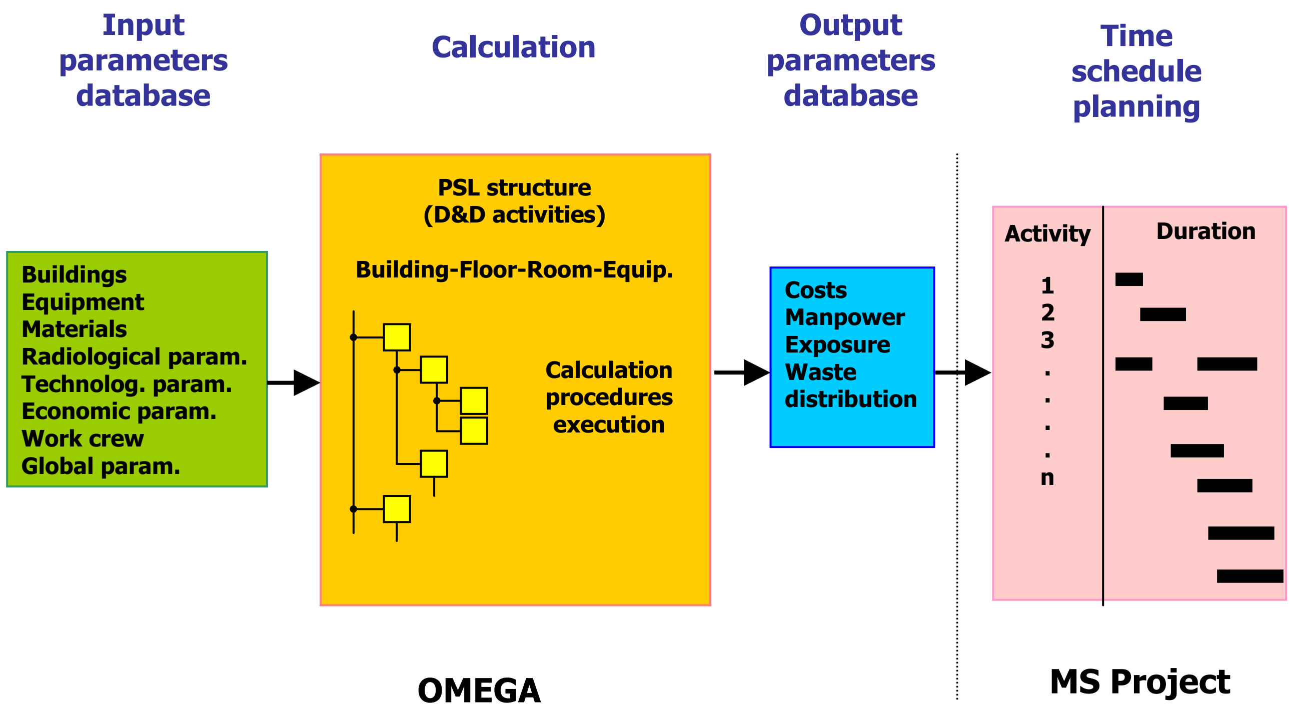


Fig. 6.4 identifies input/output data, decommissioning process calculation and its time schedule planning possibilities. Displayed OMEGA input and output databases are characterised in detail within the following sections.

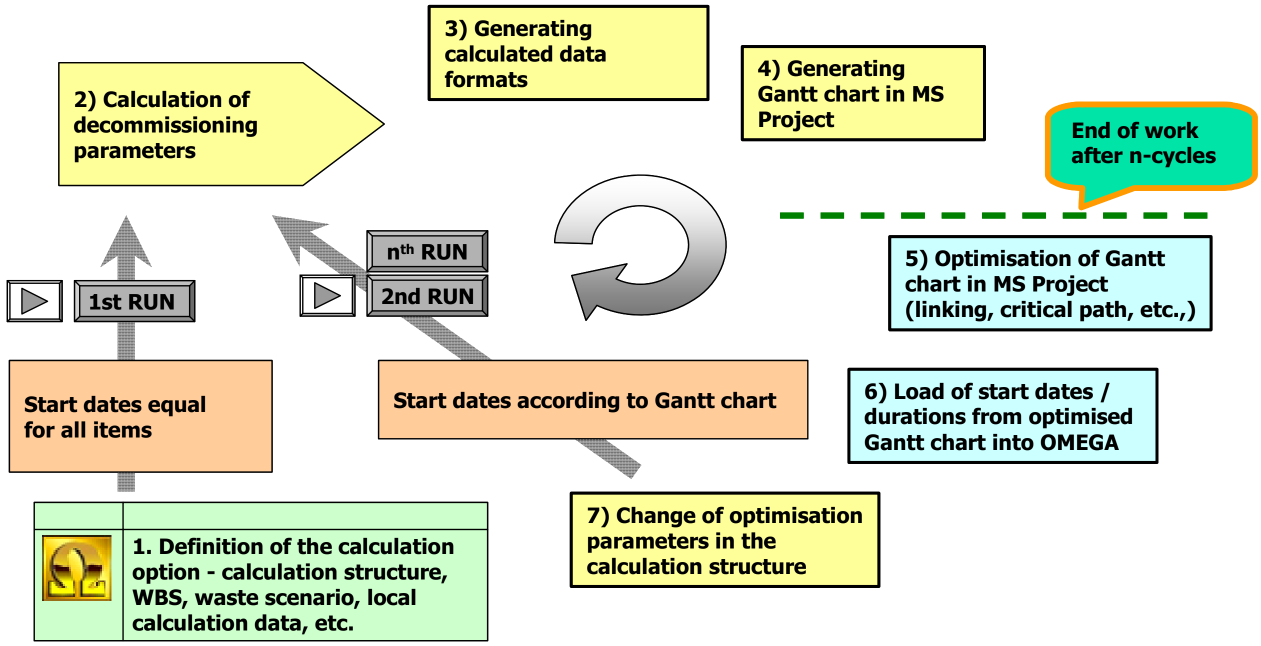
SUMMARY OF STYLE OF THE WORK WITH OMEGA

The pre-requisite for efficient work with the OMEGA code is the inventory database of the facility with relevant systems, buildings and radiological data and the calculation database with relevant data for processes, profession / work time data, material / nuclide data and other data

The work with OMEGA for management of the decommissioning calculation option has an iterative character with following main steps displayed on Fig. 6.5:

1. Definition of the calculation option - calculation structure, WBS, waste scenario, local calculation data, extent of calculation, etc.
2. Calculation of parameters in the first calculation run with equal start dates
3. Generating calculated data formats
4. Generating Gantt chart in MS Project
5. Optimisation of Gantt chart in MS Project (linking, critical path, etc.,)
6. Load of start dates / durations from optimised Gantt chart into OMEGA, change of optimisation parameters in the calculation structure
7. Calculation of decommissioning parameters with start dates derived from the Gantt chart, calculation of so called “optimised” decommissioning option. Repeated calculations with start dates derived from Gantt chart up to achieving the finally optimised decommissioning option ready for multi-attribute analysis of individually calculated / optimised / evaluated projects.

Fig. 6.5 Graphical interpretation of main steps of the iterative work with Omega



6.3.1 OMEGA input database structure

A database orientated software OMEGA uses a wide range of input database tables for obtaining requested and appropriate parameters used in process of calculation.

Whole input database table structure can be divided among several specific areas, according to the type and character of input data:

1. Building structures and technological equipment parameters
2. Material composition parameters
3. Radiological qualitative parameters
4. Technological and economical parameters of decommissioning activities (procedures)
5. Work groups and profession parameters
6. Global parameters

Individual groups of given parameters are shortly described in sections below.

1. DATABASE OF BUILDING STRUCTURES AND TECHNOLOGICAL EQUIPMENT PARAMETERS

This set of database tables describes entire decommissioned nuclear facility (ies) from the point of view of its existing building structure and technological equipment placed within this building structure. There is used a logical hierarchical structure of tables: Nuclear facilities – Buildings – Floors – Rooms – Equipment

Database of rooms describes rooms in detail by their: width, length, height and average dose rate.

Database of technological equipment is one of the fundamental input tables. It contains detailed information on technological equipment of decommissioning facilities as follows:
weight, inner and outer surfaces areas, level of surface contaminations and type of its nuclide vector, level of induced activity and type of its nuclide vector, dose rate at 0,5m far from equipment and type of its nuclide vector, dates of contamination, dose rate and induced activity measures.

2. DATABASE OF MATERIAL COMPOSITION PARAMETERS

Includes database tables which allow defining equipment by its material composition and abundance of materials within equipment:

Table of materials contains basic single materials entering the process of decommissioning, such as carbon steel, stainless steel, aluminium, copper etc.

Table of components contains list of basic equipment components. These components are parts of individual equipment categories. Each component has assigned just one type of material.

Table of equipment categories describes individual general categories into which all technological equipment in nuclear facility is divided, e.g.: categories of pipings, electro motors, valves, steam generators. Equipment category consists of set of components. Therefore all physical and radiological parameters, such as: weight, surfaces, contamination and induced radioactivity of whole individual equipment category are divided among components.

Every equipment in the Database of technological equipment has assigned just one equipment category.

3. DATABASE OF RADIOLOGICAL QUALITATIVE PARAMETERS

This part of input database deals with radiological characterization of decommissioning process and includes the following tables:

Table of nuclides is basic table that contains all nuclides being used in radiological characteristics - nuclide vectors, nuclide limits. Each nuclide has assigned its lambda constant. Currently OMEGA code includes 53 radionuclides.

Table of nuclide vectors includes nuclide vectors representing average nuclide composition (in %) of contamination, induced radioactivity or dose rate of individual technological equipment from the Database of technological equipment.
Every equipment (if contaminated or activated) has assigned appropriate nuclide vectors for its inner, outer surface, inner volume (activated) and dose rate.

Table of radiological limits contains limits used for managing materials during decommissioning process according to existing limitations. Limits are resolved on individual nuclides level. There are the following types of limits used:

- unconditional release of material
- disposal of RAW at near surface repositories
- technological limits for: high pressure compaction, melting, evaporation.

4. DATABASE OF TECHNOLOGICAL AND ECONOMICAL PARAMETERS OF DECOMMISSIONING ACTIVITIES (PROCEDURES)

This part of input database describes individual decommissioning activities represented by individual calculation procedures from technological point of view. It includes a broad spectrum of decommissioning activities carried out during decommissioning process. These parameters directly affect values of output parameters: costs, duration, manpower and amount of generated secondary waste. It includes a set of tables as follows:

Table of calculation procedures contains list of procedures representing individual activities of decommissioning. Procedures describe activities from pre-dismantling decontamination up to disposal of waste packages. Support activities (e.g. management, security, maintenance) are included.

Table of technical and economical parameters of calculation procedures is very important input table. It qualitatively describes decommissioning procedures, containing parameters of all calculation procedures directly used in calculation of procedure output parameters. Typical parameters contained in this table are: consumption unit factors, cost unit factors, capacities of equipment or work staff, waste generation unit factors, etc.

5. DATABASE OF WORK CREWS AND PROFESSION PARAMETERS

This group of input database describes composition, qualification, financial and other parameters of work staff needed for individual decommissioning procedures. It is created by the following tables:

Table of professions contains list of professions needed during the decommissioning process. There is a range of professions from top managers, through specialists, technicians to basic workers.

Each profession is specified by its costs parameters: wage, overheads and consumption costs.

Table of work crews contains a list of work crews assigned to individual decommissioning procedures. Work crew consists of assigned professions with certain number of workers. Individual professions have assigned a structure of effective and non-effective time fractions during carrying out work within individual work crew.

6. DATABASE OF GLOBAL PARAMETERS

This database table includes constant parameters for whole decommissioning facility. These parameters are independent from procedures, nuclides, materials or professions. Typical parameters are: annual workhours, over time charge, additional charge for working in ionizing radiation, average dose rate in controlled area, electricity cost unit factor, technical water cost unit factor, technical air cost unit factor, etc.

The above mentioned Input database tables are a major element of Omega code that affects its outputs. Here are some important features of Omega code concerning input database:

- Accuracy and quality of output calculated parameters depends on quality (detailness and accuracy) of input data
- Omega code is capable to calculate with more or less detailed input parameters database.
- Study level calculations – input data cannot be very detailed. Important data are: amount and composition of input decommissioned materials, basic radiological parameters, technical and economical parameters of used technologies, wages of workers, radiological limits.

It should be stressed that obtaining, modification and importing of relevant input parameters into database is a laborious activity. It represents a great portion of labour content of whole calculation process.

6.3.2 OMEGA output database structure

Omega calculates a wide range of various types of output parameters. Output parameters are calculated for every single calculation node represented by combination of decommissioning activity and building structure of decommissioned facility (especially for decontamination, dismantling and demolition). It means that the output side of calculation is created by a great number of calculated parameters for individual calculation node. Number of calculated parameters per one calculation node is in scale of tens. Number of calculated parameters values for whole facility depends on robustness of building structures and technological equipment database of decommissioned facility. The extent of calculated output parameters can gain a scale of 105 up to 108 items.

Calculation of overall output parameters is secured by agglomeration of individual items. There is used a system of characteristic parameters summation from individual nodes to higher levels of agglomeration. This system is based on PSL decommissioning structure (each D&D activity is characterised by costs, manpower and exposure).

There were created well-arranged Output forms to show structure of output parameters for whole decommissioning option and facilitate a subsequent work with them. Output forms are made in MS Excel and MS Project. Data are delivered from Oracle via ODBC and ADO standardized interface.

The computer code OMEGA produces following groups of calculated parameters:

- **General decommissioning parameters**
  - Costs, manpower, exposure, duration, amount of workers, consumption items.
  - An extended numbered fine costs structure of chapter 12 of the PSL was prepared.
- **Material parameters**
  - Parameters of interim / output materials (weight, inner / outer surface, volume, etc.) including all interim waste forms, final waste form (overpacks), released materials, gaseous and liquid effluents
- **Nuclide parameters**
  - Radioactivity of interim / output material items evaluated for individual radio-nuclides linked to each material item
- **Profession resolved parameters**
  - Manpower / exposure items resolved for individual professions of the working group
- **Time parameters**
  - Start, duration of individual decommissioning activities
- **Equipment**
  - Equipment needed for performing of individual decommissioning activities

OMEGA output parameters are chosen in such range that allows comparing influence of selected input parameters on decommissioning process and to carry out sensitivity analysis. Output parameters include characteristic parameters used in assessment of decommissioning process and can be divided into 2 main categories:

1. **MAIN GENERAL DECOMMISSIONING PARAMETERS -** these parameters characterize decommissioning option from the overall manager point of view. Costs, manpower and collective dose equivalent are included in this category.
   - **Costs -** integral parameter, sensitive to any change of input decommissioning parameters. Summarize subtotal costs items connected with decommissioning activities - labour costs, investment costs, expenses and contingency.
   - **Manpower** – represents the sum of overall work carried out during the decommissioning process and is influenced mainly by radiation situation and working conditions.
   - **Collective dose equivalent** - represents the sum of all individual dose equivalents for all decommissioning personnel. Depends on individual dose rates at workplaces during work execution and manpower needs of individual work processes.

2. **DISTRIBUTION OF MATERIALS FROM DECOMMISSIONING** - these parameters characterize decommissioning option from the dismantled and demolished material distribution point of view. This category contains mass distribution of materials destined to repositories or released into environment respectively and distribution of disposed radioactive waste containers.

   Mass distribution of materials – this parameter represents mass distribution (kg) of materials (steel, concrete, colour metals, insulation materials, debris, etc.) as a result of decommissioning process into categories as follows:
   - **Materials released to environment after dismantling** – directly released materials without application of post-dismantling decontamination.
   - **Materials released to environment after decontamination and melting respectively** – dismantled materials released after post-dismantling decontamination without or with melting.
   - **Materials destined to near-surface repository** – non-releasable materials fixed in final waste package containers for near-surface repository disposal
   - **Materials destined to deep geological repository** - non-releasable materials fixed in final waste package containers for deep geological repository disposal

   Distribution of disposed radioactive waste containers - this parameter represents numbers of containers with RAW destined to disposal at repositories:
   - **Containers destined to deep geological repository with packages** – containers contain radioactive waste destined to deep geological repository (radioactivity exceeds near-surface repository limits).
   - **Containers destined to near-surface repository with metals** - containers contain radioactive waste destined to near-surface repository (radioactivity meets near-surface repository limits).

Given output parameters (mainly costs, manpower and exposure) can be graphically displayed in the form of histograms (time behaviour of the parameter during decommissioning process).

In addition to the above described numeric values of output parameters and their graphical time behaviour, OMEGA code generates time schedule of decommissioning process determining the start time of relevant decommissioning activity and its duration – work breakdown structure of decommissioning (WBS). WBS represents a tool for optimisation of decommissioning process planning. The schedule can be optimised (e.g.: shifting of activities in time) by user in standard Microsoft Project program, load back to OMEGA code and recalculate a so-called optimised decommissioning option.

Altogether, following data formats of calculated parameters are available:

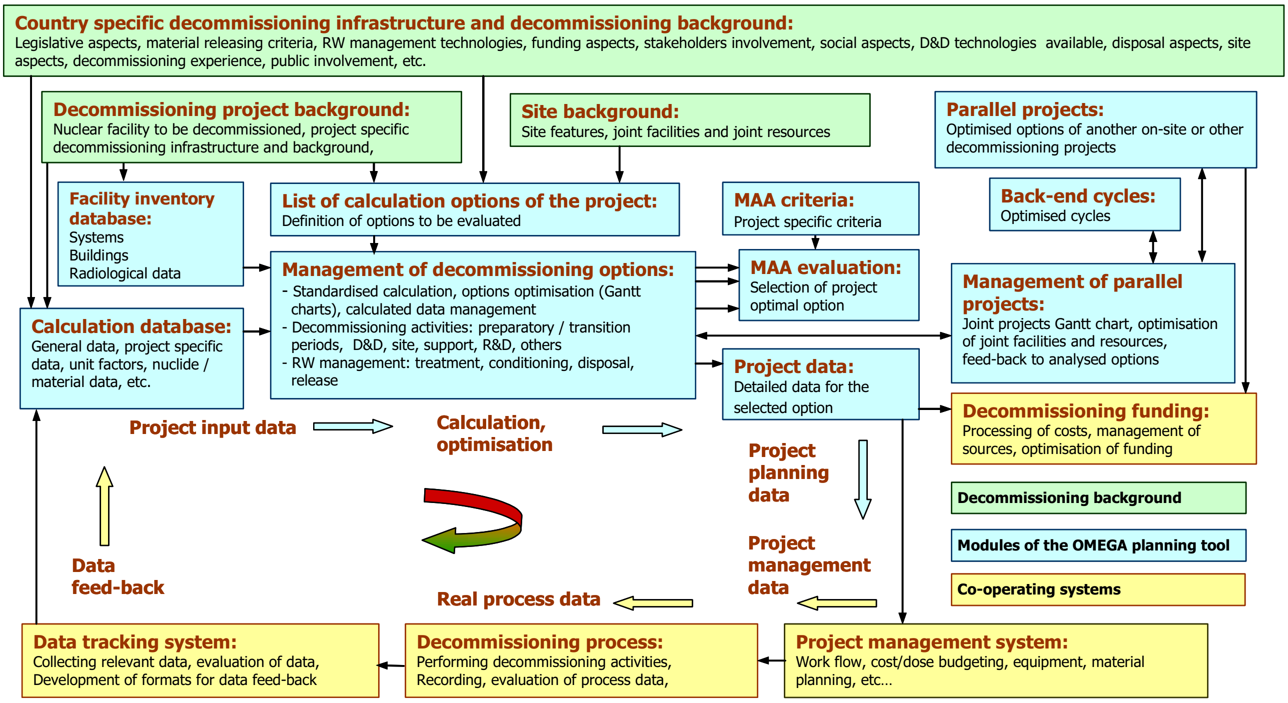
1. Detailed data review - detailed review of all calculated parameters on the level of the calculation item
2. Summary format for user selected general calculated decommissioning parameters - costs, manpower, exposure, duration, amount of workers, consumption items, etc. The data are used also for multi-attribute analysis for selection of the optimal option

3. Standardised PSL formats - table of user selected calculated parameters assembled in standardised format of PSL
4. Time graphs - time graphs with pre-selected time scale for any user selected calculated parameter
5. Gantt chart - decommissioning Gantt charts in the standard software for project planning with user selected resource parameters from the list of calculated parameters

OMEGA is the generic decommissioning planning tool for developing the decommissioning project planning data. The decommissioning infrastructure, accepted strategy, decommissioning project definition and properties of the facility to be decommissioned are the main factors with impact on developing the optimised decommissioning project and relevant project data.

The position of the OMEGA code (displayed on Fig. 6.6) is to take into account all above listed aspects for decision making process by definition a comprehensive set of calculation options which cover all aspects to be considered. All options are independently calculated, optimised and evaluated. The project planning data are then developed for the selected optimal option.

Fig. 6.6 Principal scheme for definition of the position of the OMEGA code in decommissioning data flow



The project planning data produced by OMEGA represents the base for development of project management data for detailed managing of activities involved in the decommissioning project.

The real process data, recorded and evaluated during performing the decommissioning activities are the base for correcting the data in the calculation database. This final data feed-back contributes to permanent improvement of data used for calculation of project planning data.

7. DISCUSSION ON IMPLEMENTATION OF THE ADVANCED COSTING METHODOLOGY FOR FA FACILITY IN STUDSVIK

7.1 IDENTIFICATION OF AREAS OF IMPLEMENTATION

The implementation of the advanced costing methodology using the computer code OMEGA is in general country or decommissioning project specific and represents following aspects:

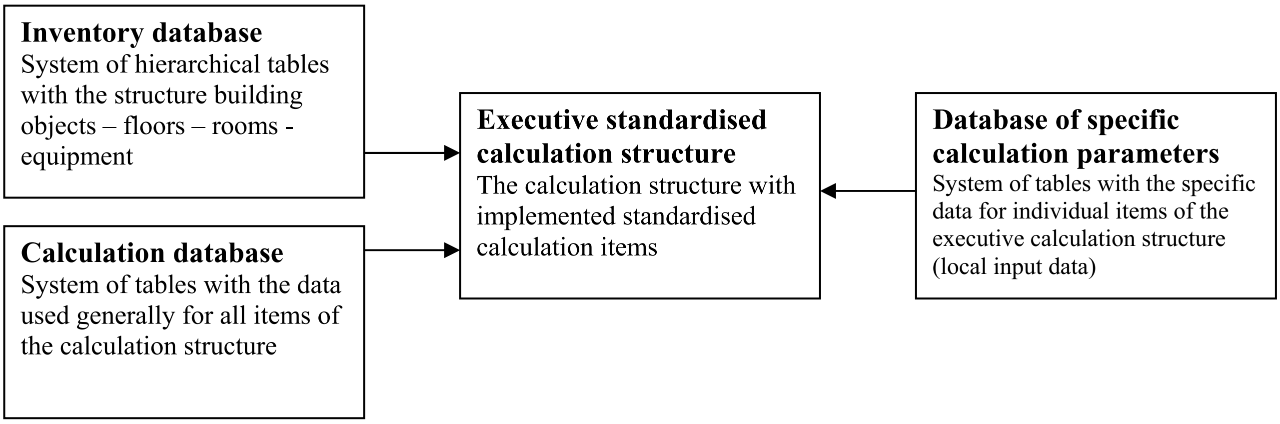
- Analyses of local decommissioning infrastructure in order to develop the relevant scenarios for management of radioactive waste and extent of decommissioning activities for relevant sections of the standardize structure.
- Development of local unit factors and other country/facility specific calculation data which should be implemented into the calculation database based on the analysis of the local decommissioning infrastructure. The local unit factors concern in general all activities for performing the decommissioning like decontamination, dismantling, waste management activities, supporting activities and others.
- Implementation of the structure inventory database with the structure according the advanced decommissioning costing methodology and implementation of the methodology for development of inventory data for the nuclear facility to be decommissioned.
- Implementation of the methodology for management of the standardized decommissioning calculation options. It means definition of extent of calculation options relevant for decommissioning project in order to evaluate all possible/considered decommissioning scenarios. The individual calculation options are then developed in their fine calculation structure, individually calculated, optimised and evaluated. The methodology of multi-attribute analysis is applied for selection of the optimal decommissioning option based on set criteria developed for the decommissioning project.

The implementation of the advanced costing methodology should consider the specific Swedish national aspects and also the specific site aspects at Studsvik. General categorization of data needed for calculation of decommissioning parameters refers to three main categories of data:

1. General calculation data like unit factors and other parameters of the technologies of the decommissioning infrastructure including the radiological data, parameters of working groups, parameters of professions, parameters of working time structure, parameters for radiation protection and other calculation parameters. These data are stored at the calculation database.
2. The identification, physical and radiological data of the technological systems and building structures to be decommissioned. The data are stored at the inventory database represented by a hierarchical database system of the nuclear facilities, buildings, floors, rooms and equipment in the rooms.
3. Specific parameters of the calculation structure. These types of calculation data are relevant for individual calculation items of the standardised calculation structure and are specific for decommissioning activities within the calculation structure. They are called local input parameters, are defined on the level of the calculation procedure and can be divided as:
    - local input parameters - increase factors, fixed cost items, number of working groups, shift work definition, duration for period dependent procedures
    - local input parameters for period dependent procedures – definition of working groups (number of workers, level of external and internal dose and protective clothes of each profession of the working group).

The basic scheme of the above listed three groups of data is presented on Fig. 7.1.

Fig. 7.1 Schematic view of relations of input database systems used for calculation of decommissioning parameters



The data for the calculation database are described in chapter 7.3. The extent of data results from the analyses of the decommissioning infrastructure, chapter 7.2. The data for the inventory database and methods for their developing are described in chapter 7.4.

7.2 ANALYSES OF LOCAL DECOMMISSIONING INFRASTRUCTURE

The goals of the analyses of the decommissioning infrastructure is:

- to identify the decommissioning activities to be incorporated into the standardized calculation structure of calculation options
- to identify the data needed for the decommissioning activities
- to develop relevant scenarios for the system of material and radioactivity flow control relevant for conditions applicable at Studsvik site

The subject of the analyses are following groups of decommissioning activities applicable at FA facility in Studsvik:

- decontamination and dismantling technologies for technological systems and building structures
- the technologies for waste treatment and conditioning like
    - fragmentation and sorting
    - liquid waste treatment (evaporation, bituminization, …)
    - supercompacting
    - melting
    - incineration
    - packaging technologies for final waste forms
- storing of waste
- final disposal of waste
- discharging of waste waters
- releasing of materials from decommissioning

The technologies available for the Studsvik site at present time should be considered and also technologies which should be installed in order to develop the system capable for performing the decommissioning activities in extent relevant to the decommissioning projects planned at FA facility.

7.3 ADAPTION OF THE DATA FOR THE CALCULATION DATABASE

The data contained at the calculation database are listed and described in chapter 5.3.1. The data are categorised as:

- material composition parameters
- radiological qualitative parameters
- technological and economical parameters of decommissioning activities
- work groups and profession parameters
- global parameters

The implementation of the advanced decommissioning costing methodology for FA facility in Studsvik regarding the calculation database represents the review of the individual database tables and adding items which are specific for Studsvik and not contained in the existing database. The extent of review is following:

Material composition parameters – completing the existing data

- single material components
- equipment components (parts of individual equipment categories)
- equipment categories

Radiological qualitative parameters – completing existing data

- List of nuclides and their lambda constant. Currently OMEGA code includes 53 radionuclides.
- List of nuclide vectors for contamination, induced radioactivity or dose rates. This type of data is extra site or facility specific and should be subject of deeper analyses. The methodology for nuclide vectors definition is presented in chapter 7.4.3. Every equipment, contaminated or activated, has assigned appropriate nuclide vectors for its inner, outer surface, inner volume (activated) and dose rate.
- Radiological limits. The data should be adjusted in view of the systems used for managing materials during decommissioning process according to existing limits The limits are resolved on individual nuclides level. Following radiological limits should be re-evaluated:
  - limits for unconditional release of material
  - limits for disposal of RAW at near surface repositories
  - limits for waste processing like high pressure compaction, melting, evaporation
  - any other limits used in waste management in Sweden

Technological and economical parameters of decommissioning activities.

- List of calculation procedures. The current list covers the calculation procedures for all typical decommissioning activities. The list should be reviewed and if there are new specific decommissioning activities, the list should be completed.
- List of technical and economical parameters relevant for each calculation procedure. If new calculation procedures were identified, also the relevant parameters should be completed for each new calculation procedure like manpower unit factors, consumption unit factors, cost unit factors, capacities of equipment or work staff, secondary waste generation unit factors, etc.

Work groups and profession parameters.

- List of professions. The list should be completed for local Studsvik conditions and the parameters of new professions should be added. The most important parameters are the labour costs specific for each profession.
- List of work groups. If new calculation procedures or new professions were identified, also new work groups should be defined or existing work groups should be modified. Work group consists of assigned professions with identified number of workers of each profession. Individual professions have assigned a structure of effective and non-effective time components during carrying out work within individual work group.

Global parameters.

This database of existing data should be reviewed. There is lot of data which are country or even site specific especially the cost unit factors like cost for electricity, water, steam and other basic technological media.

7.4 THE INVENTORY DATABASE

7.4.1 General considerations.

The phase of collection of the data is the initial stage of developing the decommissioning database [8]. The collected data should be structured in such a manner that the generation of the decommissioning database would be feasible, the database remains open for other additional data and also the database should be up-gradable also during the future use. From this point of view, it is very important to fix the structure of the database at the early stages of their developing. Corrections of the structure of the database in later phases would be problematic.

The decommissioning database should correspond also to the methodology of calculation of decommissioning parameters. There are several general methodologies which differ in:

- level of details calculation items,
- extent of decommissioning activities
- calculation formulas for algoritmisation of decommissioning activities
- calculated parameters
- principles of management of waste
- implementation of the standardised costs structure for decommissioning
- management of exposure calculation
- other aspects.

The methodology of calculation of the decommissioning parameters should be known at the early stages of developing the decommissioning database which should contain all input data needed for selected methodology of calculation of the decommissioning parameters.

The idea to use the operating personnel is the good idea, because the operating personnel knows the facility best. But this is only one of the sources of data for the decommissioning database. The concept of calculation of decommissioning parameters for decommissioning planning is developed by the personnel with specialisation for decommissioning and these people see the facility from other point of view. Therefore it is necessary to ensure the operating personnel and the specialist preparing the decommissioning work in parallel for a sufficient period.

The facility information systems used during the operation of the facility contains a lot of data which are needed also for preparing the decommissioning like the parameters of equipment, radiological data of contamination, dose rates and other data. It is recommended to develop also the system for collecting the data from these operational databases and to develop the methodology for converting the data from the operating database into the decommissioning inventory data if such an information system exists.

As for the equipment data, it is recommended to use the concept of categorisation together with the developing the additional data related to the individual categories of equipment. This concept enables to upgrade the database in the future in order to increase the accuracy of calculation of decommissioning parameters by increasing the accuracy of inventory data.

The concept of management of radiological parameters during the calculation process which deals directly with the radiological parameters of waste during the calculation process is an important issue which can increase the accuracy of calculation. When selecting a good concept, the effect of time can be incorporated into the calculation of decommissioning parameters (e.g. parameter changes between immediate and deferred dismantling) and also various schemes of decommissioning scenarios and the scenarios of waste management can be evaluated. The decommissioning database should contain the data needed for the concept.

Implementation of the standardised costs structure into the system of decommissioning planning is one of the issues of highest importance nowadays. This requires developing the relevant structure of the decommissioning database applicable for standardised costing. The structure should be known already at the stage of preparing the system for collecting the data for the decommissioning database.

The above listed issues should be taken into account already in early stages of preparing the decommissioning inventory database. All these aspects are met when implementing the advanced decommissioning costing using the OMEGA code.

The implementation of the advanced costing methodology at Studsvik requires developing the inventory database for the facility in the structure described in this chapter.

7.4.2 General procedure for developing the inventory database

The inventory database should contain in general following type of data for each database item:

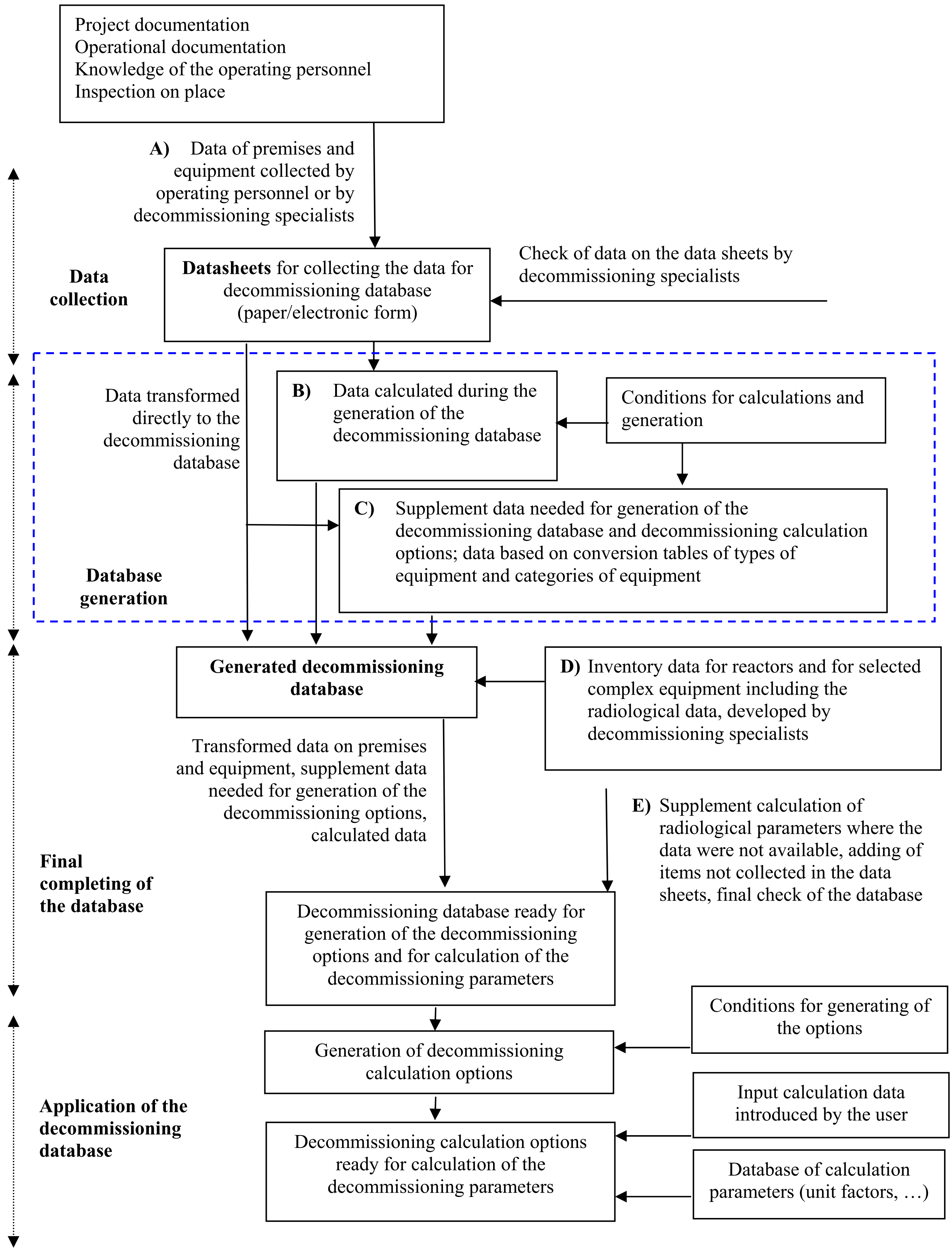
- identification data
- description data
- relevancy to the technological systems and building structure systems
- physical data
- radiological data
- categorisation data needed for streaming the resulting waste
- data for generation of the standardised calculation structure.

From the point of view of the decommissioning, the structure of database data should reflect factors like:

- the structure of decommissioning activities to be performed
- the time sequence of performing the decommissioning activities
- the structure of decommissioning activities defined in „A Proposed Standardised List of Items for Costing Purposes in the Decommissioning of Nuclear Installations" [3].

The above listed parameters are more familiar to the personnel involved in decommissioning planning. The decommissioning database is in general developed in several steps. The simplified scheme with identification of individual phases of preparation of the decommissioning database is presented on Fig. 7.2.

Fig. 7.2 Principal scheme of basic phases for the development of the decommissioning database



There are various types of data from “A” to “E” identified on Fig. 7.2, where:

Data of “A” type are the primary data to be collected. The data can be collected by using the data sheet developed for this purpose or the data can be transferred from other databases, for example by their filtering and converting from the facility operation database. Another possibility is the direct input by the decommissioning experts into the developed decommissioning inventory database.

Data of “B” type are the secondary date derived from the primary data by calculation. This type of data is developed either during converting the data from other database, from datasheets or by direct calculating during manual entering of the data.

Data of “C” type are the data used in the generation of the calculation database and in generation (or definition) of the decommissioning calculation options. This type of data is again developed either during converting the data from other database, from datasheets or by direct calculating during manual entering of the data. These data are especially important in implementation of the standardised cost item structure.

Data of “D” type are the complete inventory data for reactor structures, developed in separate tasks. Preparation of this kind of data requires additional complex calculations like neutron flux calculations, calculation of activation of reactor construction of materials, development of a hierarchical inventory database structure which corresponds to proposed dismantling procedure. Similar attitude is used also for other complex equipment like steam generators, volume compensators, primary piping and other equipment. This kind of data should be prepared by decommissioning specialists.

Data of “E” type are in general the radiological data, mostly the contamination levels and the nuclide composition of contamination or dose rate. These data are in general calculated because there are limited information on radiological properties of technological equipment. The data on contamination is collected by sampling for limited extent of equipment and building structures and based on belonging of the equipment to technological systems, these data ere extended to all equipment grouped to systems, based on data of the dose rate in defined distance from the equipment. It is assumed that the main radiological parameters – the dose rate in the defined distance (e.g. 0.5 m) from the equipment is collected in the frame of collecting the primary data by the operational personnel. The contamination data can be then calculated based on calculation models of categories of equipment, when they are not available as the primary data. The nuclide composition can be derived from radiological analysis of relevant samples.

7.4.3 Radiological data

Impact of nuclide composition and level of radioactivity on decommissioning is significant and determines the choice of decommissioning activities (manual/remote, etc.), the amount and parameters of waste, its processing and disposal and modifies significantly the decommissioning costs, exposure, manpower and other decommissioning parameters, especially in the case of a facility with non-standard radiological situation like after an accident. Therefore the radiological parameters play an important role in developing the inventory database. It is important to note that the inventory data is this type are not present in SVAFO decommissioning study.

In this chapter are described the principles of defining and using the radiological parameters in the calculation code OMEGA developed at DECOM Slovakia which implements the calculation modelling of the decommissioning process. The recommendations are based on experience collected during application of this code in standardised decommissioning calculations which proved unique properties of the code. The radiological parameters used by this code are nuclide resolved and the principle of nuclide vectors was used for definition and management of the radiological parameters. The nuclide vectors represents the normalised composition of individual radio-nuclides for a given radiological parameters.

The radiological parameters used for the decommissioning inventory items are following:

1. Surface contamination of inner surfaces
   - Total value of the contamination [Bq/m^2]
   - Date of the definition of the total value of the contamination
   - Nuclide vector of the contamination (ID from the table of nuclide vectors).
2. Surface contamination of outer surfaces
   - Total value of the contamination [Bq/m^2]
   - Date of the definition of the total value of the contamination

– Nuclide vector of the contamination (ID from the table of nuclide vectors).

3. Dose rate in the working distance (0,5 m) from the inventory item
   – Total value of the dose rate [microGy/h]
   – Date of the definition of the total value of the dose rate
   – Nuclide vector of the contamination (ID from the table of nuclide vectors).
4. Induced/mass activity
   – Total value of the dose rate [Bq/kg]
   – Date of the definition of the total value of the dose rate
   – Nuclide vector of the contamination (ID from the table of nuclide vectors).

The radiological parameters used for the premises - Dose rate in the room:

– Total value of the dose rate [microGy/h]
– Date of the definition of the total value of the dose rate
– Nuclide vector of the contamination (ID from the table of nuclide vectors).

To the **basic set of radiological data** belong also the database tables for nuclide vectors with following data:

– List of nuclide vectors
– Normalised abundance of individual radio-nuclides for each nuclide vector
– Date of definition of the nuclide vector
– Parameters of individual radio-nuclides (lambda constant).

The above presented structure of the radiological inventory data enables to implement the material and radiological aspects into decommissioning cost calculation by following algorithmisation:

1. Algorithmization of the entire material flow in decommissioning by calculation modelling in order to on-line optimise the decommissioning and waste management.
2. Algorithmization of radiological aspects in order to manage the flow of radioactivity linked to the material flow and to manage the effect of time in decommissioning (to implement the impacts of radioactive decay).

These two principles enable to increase the accuracy of calculation of decommissioning parameters related to material flow in decommissioning, enable to optimise the waste management and to perform the sensitivity analysis.

The concept of the nuclide vectors enables to work with actual values of individual radio-nuclides in the process of calculation of decommissioning parameters. The actual values mean that the radiological parameters are recovered due to individual decay and in this way the effect of deferred decommissioning can be evaluated directly. Another advantage of working with individual radio-nuclides is that the nuclide resolved limits for technological process for treatment and conditioning of radioactive waste, for disposal of conditioned waste and for release (unconditioned or conditioned) can be applied. This enables to assemble the sequence of the calculation process in such a manner that it can simulate the real flow of material and radioactivity in the decommissioning process. The real values of radiological parameters used for calculation are derived in the initial stages of the calculation procedures dealing with radioactivity.

The concept of nuclide vectors enables the management of material / radioactivity flow in decommissioning by definition of calculation sequence and by data linking of calculation procedures (calculation modelling of decommissioning process). The concept of material / radioactivity flow control in decommissioning applied in the code represent an original generic methodology and tools implemented into the standardised OMEGA code for on-line optimisation of decommissioning and waste management processes with following principles:

- The modelling of the processes is based on mathematical material partitioning of inventory items into one-material elements which enter into the pre-defined sequence of calculation / sorting procedures linked each other by unambiguous material links
- To each one-material calculation element are linked radiological parameters which are generated during the material partitioning. The generation is based on the calculation category of the inventory items and distribution coefficients relevant for the item category

- The linked radiological parameters are during the calculation dynamically recovered to the start dates of individual decommissioning activities. The decay of radioactivity of individual radio-nuclides is respected through the entire decommissioning process.
- The sorting procedures implement the limits for releasing of materials, acceptance limits for disposal of materials, acceptance limits for individual process (if they are defined) and parameters of individual processes which affect the material / radiological parameters of evaluated items
- The calculation procedures can be linked to pre-defined scenarios of waste management for decommissioning starting from pre-dismantling decontamination up the release of materials or disposal of materials on the surface repository or deep geological repository
- Multi-stream material calculation structures can be defined by appropriate sequence definition combined with selected sections of standardised calculation structure and by definition of dates for waste entry into individual material streams. The waste streams are optimised in a standard Microsoft Project software
- Keyboard data entry of waste items for general application in waste management modelling and optimisation is feasible.

The above mentioned concept of definition of radiological parameters in the decommissioning inventory database enables also to use additional important features of the advanced costing methodology due to internal linking of the calculation process, i.e. the possibility to perform the sensitivity analysis which can reveal the hypothetical margins and trends of decommissioning costs and other decommissioning parameters by considering various calculation conditions, effect of time, etc. The input parameters for varying could be:

- Level of contamination of equipment and the radio-nuclide composition of the contamination - to study the effect of the quality of the operation, effect of accidents, impacts of limits for disposal or release vs. nuclide composition, etc.
- Start date of decommissioning activities - to study effect of deferred dismantling and related issues
- Scenarios of RAW management - to study effect of extent and/or parameters of waste management technologies
- Application of pre-dismantling decontamination - to study the effect of extent of decontamination and effect of the value of decontamination factors
- Labour cost or other parameters - to study the effect of selected local factors

The sensitivity analysis of this type can be effectively used at the stages of decision-making processes in decommissioning planning for evaluating the possible scenarios of decommissioning.

7.4.4 Inventory database data for implementation of the standardised cost calculation structure

In the chapter are summarised the recommendations for implementing the standardised structure for decommissioning purposes which was issued by OECD/NEA, IAEA and EU in 1999 in the document "A Proposed Standardised List of Costs Items for Decommissioning Purposes" (PSL) [3]. The document defines the structure of decommissioning activities for which the costs are to be presented. It is recommended that implementation of the "Proposed Standardised List of Items for Costing Purposes in the Decommissioning of Nuclear Installations" should be respected in the early stage during the development of the decommissioning database.

The standardised cost structure represents in principle the system of decommissioning activities structuralised in above listed chapters. The main aim was to develop a structure for presenting the costs for decommissioning, but at the same time it can be used for presenting also other decommissioning parameters for presenting the decommissioning projects. From this point of view (systems of decommissioning activities) the standardised structure can be used as the base for the calculation structure for calculation of costs and other decommissioning parameters. Those issues of the individual decommissioning projects which are project specific, like the decommissioning work breakdown structure, can then be constructed using the items of the standardised calculation structure.

The calculation structure used for the calculation of costs and other decommissioning parameters is in general the result of the interaction of the list of decommissioning activities to be done within the decommissioning project and of the inventory database. It means that sets of room-oriented decommissioning activities are repeated according to the structure building object – floor – room and set of decommissioning activities are generated for each inventory item within the room. Such a structure is repeated in various sections of the calculation structure for typical decommissioning activities like dismantling, decontamination of building surfaces, radiation monitoring of premises and other activities.

Other sections of the calculation structures are independent on the inventory database and have their own conditions for generation of calculation items.

The standardised calculation structure for calculating of the decommissioning parameters is characterised by the fact that it implements the published structure of decommissioning activities and in relevant sections (for example for dismantling) it uses for the elements of the decommissioning inventory database for generating the individual calculation items. Therefore the structure of the decommissioning inventory database should reflect also this requirements, it means that it should contains also the data needed for the generation of the standardised calculation structure.

The standardised calculation structure has also some special features which reflect the fact that the similar or the same decommissioning activities (again for example dismantling) are distributed in more independent sections. The decommissioning inventory database items should facilitate the generation of the standardised calculation structure also for these cases.

The implementation of the standardised structure of decommissioning activities for FA facility in Studsvik, in order to generate the standardised costs structure, requires that following data should be included into the inventory database:

- **Type of the building object**. The parameter is used for generation of sections of the standardised calculation structure relevant for nuclear building objects with reactor, without reactors or non-nuclear facilities especially in chapters 4 and 7 of the definition of the standardised structure.
- **Type of the decommissioning inventory item**. The parameter is used for the definition of the group of the equipment like types of the building surface or types of the technological equipment. The data are used for definition of the section of the standardised structure where the database items are to be implemented.
- **Category of the decommissioning inventory item**. The parameter is used for selection of the calculation procedure for the item of the calculation structure and for selection calculation data dependent on the category.
- **Number of the item of the standardised structure (PSL number**) – a number from the detailed standardized structure used for generation of the calculation structure of the decommissioning option. The parameter is used for definition of the calculation item within the detailed numbered standardisation structure. The data are used for definition of the calculation structure for special items defined in standardised calculation structure like reactor structure, refuelling machines, etc.

7.4.5 Proposed structure of the decommissioning database

The full proposal of the decommissioning inventory database, unit factor and other calculation data are presented in Annex 1 and Annex 2. The implementation of the advanced costing methodology involves also the delivery of the database structure. The database can contain the sample data which can be used as specimen (master) data for developing the inventory data of the technological systems and building structure.

7.5 IMPLEMENTATION OF THE STYLE OF WORK WITH THE COMPUTER CODE OMEGA

Implementation of the work style with OMEGA code represents following individual phases of decommissioning costing applicable for FA facility:

1. Description of the facility related to decommissioning
   - Study of the facility documentation, history of operation,
2. Development of the description of the facility relating to decommissioning
   - Technical description of technologies and buildings
   - Radiological description
3. Inventory of the nuclear facility for decommissioning
   - Technological and building inventory and relevant radiological parameters (contamination, activation, dose rates, nuclide vectors):
     - * The inventory at the level of a feasibility study - individual technological systems and the contamination classes for individual systems
     - * The inventory at a detailed level with the structure building objects – floors – rooms - individual items in the rooms (technological equipment, building materials, building surfaces)
   - Concept of contamination classes enables the use of material and radioactivity flow control system of Omega also on the level of the feasibility study
   - Calculation methods for estimation of the level of contamination, derivation of nuclide vectors from existing data or by comparing with similar facilities or as the most conservative cases
4. Analysis of the decommissioning infrastructure within the decommissioning project
   - Review of the actual state in decommissioning related to the project
   - Review of technologies available / recommended for the project
   - Review of cost factors and other unit factors,
   - Development of the database with costs factors and parameters of decommissioning technologies

5. Management of decommissioning options
   - Definition of decommissioning options and their structure
   - Inventory of decommissioning activities
   - Development of the database for period dependent activities and fixed costs
   - Development of standardised calculation structures for individual options
   - Calculation, optimisation, evaluation of individual options
   - Comparison of options, selection of an optimum option based on multi-attribute analysis

6. Presentation of final results
   - Review of options that were analysed
   - Review of final comparisons and selection of options
   - Detailed presentation of selected options.

8. CONCLUSIONS

Within the frame of the project an analysis of decommissioning cost estimates prepared by SVAFO for Intermediate Storage Facility for Spent Fuel (FA) facility in Studsvik was performed. Subsequently reported summarised input data, SVAFO cost estimates methodology and summarised results of the SVAFO study were discussed.

The SVAFO kind of study is generally used in preliminary stages of decommissioning preparation however more detailed cost estimates should be used for further steps of decommissioning planning of FA facility. In these steps also radiological parameters (dose rates, contamination, radionuclide composition) should be considered in calculation of decommissioning parameters. The inventory database from SVAFO study (data of technological systems and building structures) after its upgrading and appending absent radiological parameters (see chapter 5 - Conclusions from the analysis of the SVAFO study for FA facility in Studsvik) and additional data for generation of standardised calculation structure can be used for development of the upgraded version of FA facility decommissioning study.

Under these assumptions also variant calculations of decommissioning parameters can be performed. In order to implement the advanced cost estimating methodology (OMEGA code) for FA facility it would be necessary to consider site specific issues, such as:

- local decommissioning infrastructure implemented into decommissioning scenarios specific for FA facility
- local unit factors and other country specific calculation data
- inventory database for FA facility developed with the structure relevant for the advanced costing methodology

This approach after successful application can be used as a pilot case for implementation of the advanced costing methodology.

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10. ANNEXES

Annex 1: Inventory Database Tables

Annex 2: Unit Factors and Other Calculation Data www.ski.se

STATENS KÄRNKRAFTINSPEKTION
Swedish Nuclear Power Inspectorate

POST/POSTAL ADDRESS SE-106 58 Stockholm
BESÖK/OFFICE Klarabergsviadukten 90
TELEFON/TELEPHONE +46 (0)8 698 84 00
TELEFAX +46 (0)8 661 90 86
E-POST/E-MAIL ski@ski.se
WEBBPLATS/WEB SITE www.ski.se