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Deterministic Assessment of Future Costs for Dismantling (FA)

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Abstract

In this study a model for advanced deterministic cost calculation has been used to find a parametric value on the cost for dismantling of the FA-facility. The study gives good description of good practise to collect, test and utilise input data in a systematic way in order to make prudent cost estimates for any particular nuclear installation

Background

The Swedish Law stipulates that future expenses for dismantling of older nuclear installations and associated radioactive waste management shall be financed by funds generated under the so-called "Studsvik Act". The task to inject sufficient capital into the Swedish Nuclear Waste Fund is fundamental for the trustworthiness as well as sustainability of the Swedish model for financing of radioactive waste for older nuclear installations.

Objectives of the project

The aim of this study has been to do a deterministic cost assessment of the FA-facility at the Studsvik Site using actual Swedish unit factors for costs of labour, as well as other relevant entities such as consumables, materials and substances. Moreover, one sub-goal was to demonstrate a comprehensive procedure for collecting input data at an early stage of decommissioning projects, and to show that a high degree of accuracy.

Results

The study discloses that accurate cost assessment can be made with the help of a deterministic model, the OMEGA code. This report also demonstrates that active learning processes of advanced costing methodology is a tool for identifying qualified parametric data and thereby enhancing the over-all robustness and precision of future cost assessments. Calculation uses the same FA facility inventory database and presents output parameters in the same way as the former tentative calculation using standardized decommissioning cost calculation structure Proposed Standard List, PSL, recommended for application in decommissioning costing by the main European organizations involved in decommissioning (IAEA, EC and OECD/NEA).

Conclusions

The used of up-dated input Swedish figures has resulted in a total cost for dismantling of the FA-facility of € 7,9 millon - which is an increase with well over 80 %. This increase is caused mainly by higher Swedish labour cost unit factors which are significantly higher than formerly used Slovak ones and also by increase of consumables and other cost factors which are, in common, higher in Sweden comparing to Slovakia. New updated calculation may even be further optimised by upgrading of the FA Facility inventory database e.g. technological and mainly radiological inventory characterization, also by implementation of Swedish waste management infrastructure into OMEGA database and calculation procedures including final disposal at Swedish repositories with up-to-date costs of disposal per m^3.

The report results show that once a decommissioning project was calculated by OMEGA software it can be adjusted and optimised further with regard to changed input conditions and comparison with previous results is easily possible.

Project information

At DECOM, Slovakia, Marek Vasko has been responsible for the co-ordination of the project. Staffan Lindskog has initiated, defined and been responsible for the steward-ship of the entire project.

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Content

Abstract

The main objective of the report is to provide an re-evaluation of cost calculations by OMEGA code for the Intermediate Storage for Spent Fuel in Studsvik (FA facility) using up-to-date Swedish labour cost unit factors and available up-to-date Swedish (or international) cost unit factors for consumables, materials and substances. Furthermore, evolution of other OMEGA database parameters concerning cost calculations e.g. manpower unit factors and workgroups parameters are taken into account.

This report follows up former project which introduced tentative calculations of main decommissioning parameters such as costs, manpower and exposure of personnel for activities of older nuclear facility decommissioning in Sweden represented by FA Facility in Studsvik by means of calculation code OMEGA [1]. The project demonstrated an implementation of advanced costing methodology based on PSL structure format to achieve transparent, traceable and comparable estimates even for older nuclear facilities like FA Facility in Studsvik. This former project used Slovak origin labour costs unit factors and other cost unit factors.

After successful completion of this project, there was an intent of SSM to re-evaluate calculations using an up-to-date Swedish labour cost data and also available Swedish consumables and materials cost data if available. Within this report re-calculations of main decommissioning parameters using available Swedish data are presented in structure according to Proposed Standardized List of Items for Costing Purposes [7]. Calculations are made for decommissioning scenario with post-dismantling decontamination and steel radwaste melting technologies available at the site. All parameters are documented and summed up in both table and graphic forms in text and Annexes. Further, comparison of calculated results with previous calculations in [1] together with discussion is provided.

Abbreviations

CC	-	contamination class
CS	-	carbon steel
EU	-	European Union
FA Facility	-	Intermediate Storage Facility for Spent Fuel in Studsvik
FRC	-	fibre reinforced concrete
IAEA	-	International Atomic Energy Agency
LLW/ILW	-	Low Level Wastes/Intermediate Level Wastes
LRAW	-	Liquid RAW
NPP	-	Nuclear power plant
NSR	-	Near surface repository
OECD	-	Organization for Economic Co-operation and Development
PP	-	polypropylene
PSL	-	A Proposed Standardised List of Items for Costing Purposes
RA	-	radioactive
RAW	-	radioactive waste
SS	-	stainless steel

1. Introduction

The planning and implementation of decommissioning strategies for nuclear facilities requires a careful cost calculation analysis of the whole process. Since the number of decommissioning projects has increased an application of standardised cost structure seems to be a solution in order to achieve transparent, traceable and comparable results with various decommissioning projects in various countries.

This report is the further continuation of former Swedish Nuclear Power Inspectorate (SKI) and today′s Swedish Radiation Safety Authority (SSM) successful cooperation with Slovak team of decommissioning experts since 2004 represented by number of projects [2], [3], [1].

The study below continues on calculations performed within the SKI project "On tentative decommissioning cost analysis with specific authentic cost calculations with the application of the OMEGA code on a case linked to the FA Facility in Sweden" [1] from 2007. Calculations in this project were performed in OMEGA code which implements advanced costing methodology approach using PSL [7] as a fundamental structure for calculation, assortment and presentation of calculated figures. Main objective in the study was to demonstrate the trial application of OMEGA code for older nuclear facility decommissioning costs evaluation and its suitability for such deployment. Main input cost drivers such as labour costs and consumables were taken from Slovak available figures in the study. From this reason there was an intent of SSM to re-evaluate these calculations using an actual Swedish labour costs data and also Swedish consumables and materials cost data if available. Calculations were made for decommissioning scenario with post-dismantling decontamination and steel radwaste melting technologies available at the site.
Structure of this new project report comes out from structure of former project report to provide reader with basic information on FA Facility inventory details and databases, basic OMEGA code characteristics, considered decommissioning activities and waste management implemented in OMEGA code, and systematic of calculation based on PSL structure. Further information on changes in input database parameters comparing to previous calculations are provided. In the last chapters of the document, new calculated figures are presented and compared with figures from previous project calculations.

Within the project, new up-to-date figures on Swedish labour costs were obtained. Other Swedish cost unit factors (consumables, materials, substances unit costs) were not available therefore they are substituted with available international figures. Since no new information on FA Facility status is known from 2007, new project uses the same inventory database as were used in former project calculations including physical and radiological characteristics of FA Facility equipment and premises. Concerning waste management infrastructure, new calculations are performed for radioactive waste treatment scenario with wet bath post-dismantling decontamination equipment for iron/steel radwaste and melting equipment for iron/steel radwaste available at decommissioning site. Main decommissioning parameters such as costs, manpower, collective dose equivalent and distribution of materials arisen from decommissioning are calculated for above mentioned radioactive waste treatment scenario. Essential input parameters including labour costs unit factors, other unit factors, main procedures parameters, as well as output parameters such as manpower, cost, exposure listed in PSL structure together with a time schedule of calculated decommissioning activities for FA Facility in MS Project are provided in Annexes 1 to 5.

2. Calculations by the Omega Code

This chapter gives a short characteristics of FA Facility as an object of decommissioning re-calculations and describes main features of decommissioning calculation code OMEGA. At last a brief information developed in detail in further chapters on extent and conditions for decommissioning calculations is also provided.

2.1. Short Description of FA Facility

In previous project [1] FA Facility in Studsvik was chosen as an example of older nuclear facility for the tentative decommissioning calculations. The reason for the choice was an information on technological and building inventory taken from available documentation [4], obtained results from the previous research project for SKI carried out in 2005 [3] and information taken from technical visit of FA Facility in 2005.

FA Facility is a relatively small building located within Studsvik site, and it was used as an intermediate underwater storage facility for spent fuel from the Ågesta reactor. It was designed and built during 1962-1964 [4]. 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 [6]. Former stored fuel has originated from R1 reactor in KTH Stockholm, R2 an R2-0 reactor in Studsvik and reactor in Ågesta.

As an interim spent fuel storage 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.

Concerning the radiological situation, Co-60 is expected to be the main contaminant of FA Facility [3]. 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 [4]. These values indicate the need of decontamination for a great portion of equipment surfaces to meet the release criteria according to regulation SSMFS:2008:39 [17].

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 kBq/m^2 (α) [4].

In the case of decontamination basin it is assumed that radioactivity 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 used a method of conversion factors between surface dose rate measurements and specific activity of given component.

Available data are rather descriptive therefore the conservative approach for definition of radiological properties was applied (Chapter 3.1.4.)
Concerning the end point status of FA Facility a green field is considered with remediation and landscaping of area after final demolishing of building.

2.2. Brief Description of Decommissioning Cost Calculation Code Omega

For the performance of re-calculation of FA Facility decommissioning parameters, planning Omega calculation code has been used as well as for the former tentative cost calculations in [1].

The computer code OMEGA was developed by DECOM Slovakia and it is an option oriented calculation and optimization code for applications in decommissioning decision making processes for nuclear facilities of various types and radiological properties with following purposes:

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

Basic properties of the calculation code OMEGA for applications on the level of the calculation options [3]:

1. Activity based costing was implemented based on the Proposed Standardised List of Costs Items (PSL) [7] issued commonly by OECD, IAEA and EC which enables to use the code for various types of nuclear facilities.
2. 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.
3. The code was originally 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 radioactive waste management. The code can be used for facilities with various radiological states. The accuracy of calculation of decommissioning parameters is significantly higher than using the traditional costing methodologies where the amounts of waste are estimated.

4. The calculation process is nuclide-resolved. This enables to use 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.
5. 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.

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.

Main calculated parameters are costs in standardised PSL structure, manpower and exposure items (total values and profession resolved items), material items and nuclide resolved radioactivity items linked to these material items (so called waste distribution), time parameters such as starts and duration of elementary activities and of phases of the process and equipment planning items.

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

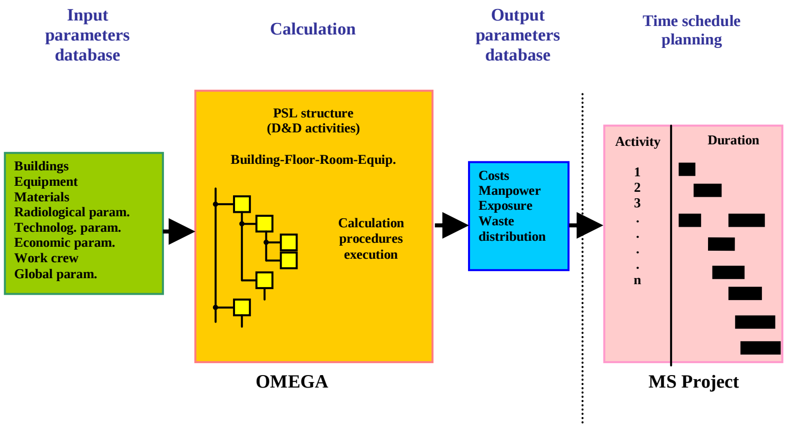


Figure 0-1 Simplified scheme of OMEGA data processing

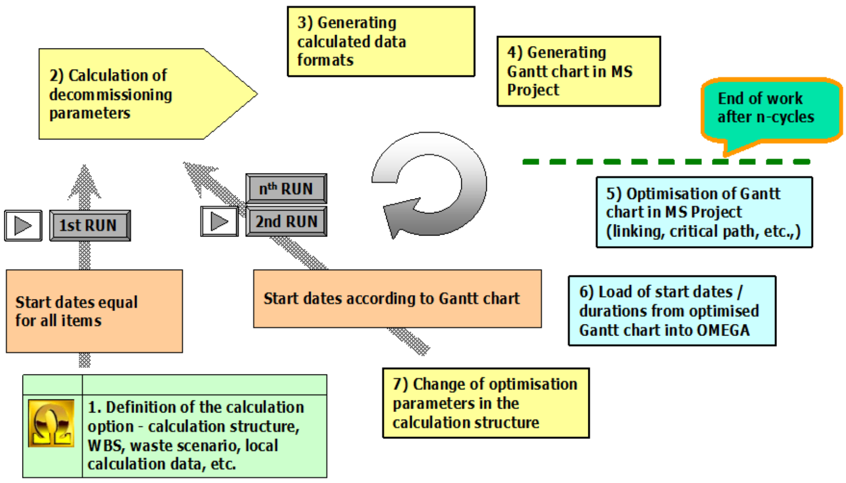
Figure 0-1 identifies input/output data, decommissioning process calculation and its time schedule planning possibilities. Displayed OMEGA input database applied in tentative decommissioning calculations for FA Facility are characterised in detail within Chapter 3.

The work with OMEGA for management of the decommissioning calculation option has an iterative character with following main steps displayed on Figure 2- 2:

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.

Figure 0-2 Graphical interpretation of main steps of the iterative work with Omega



Principles of algoritmisation of costs calculation in Omega can be summarised as follows:

a) What to do - management of the standardised calculation structure. Definition of decommissioning activities and extent of calculation
b) How to do - management of calculation conditions. Definition of calculation procedures, definition of local calculation input data and correction factors
c) 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)
d) 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.

2.3. Conditions for Decommissioning Re-Calculations

For former tentative decommissioning calculations using OMEGA code, an inventory database of FA Facility comprised in SVAFO decommissioning study [4] was used as the primary source of input data. The results from analyses of the SVAFO study for FA Facility documented in the previous research project [3] were also taken into account as the source of information, especially the part devoted to the "Discussion on input data". Since no new information on FA Facility status is known after former project successful completion, new calculations come out from the same conditions and information as well. Separate Chapter 3 describes development of input database for FA Facility in Studsvik.

Comparing to previous tentative calculation using original Slovak labour costs and Slovak consumables cost unit factors were used, re-calculated evaluation uses new up-to-date Swedish labour costs and cost unit factors derived from international market prices.

Parameters characterizing the decommissioning process and its individual activities (manpower unit factors, equipment capacities, consumption unit factors, workforce) from preparatory activities through dismantling up to waste treatment and disposal of radioactive waste were updated according to available actual international information. For waste management, Slovak end points and conditions, repositories or release into environment together with their radiological limits and other parameters are applied.

Decommissioning activities included in the re-calculations for FA Facility are of the same extent as were in original calculations and are divided into following categories:

- Preparatory activities.
- Dismantling activities.
- Decontamination of building surfaces.
- Final building radiation survey.
- Post-dismantling decontamination of technological equipment.
- Waste management activities: Sorting of dismantled material, treatment and conditioning activities of dismantled material, packaging, transportation and disposal activities.
- Demolition, site restoration and release of the site.
- Management and support decommissioning activities.

Main features of individual decommissioning activities included in re-calculations for FA Facility by OMEGA code are described in more detail in Chapters 4 and 5.

Re-calculations of FA Facility decommissioning by OMEGA code is evaluated for waste treatment scenarios with wet bath post-dismantling decontamination equipment for iron/steel radwaste and melting equipment for iron/steel radwaste are available at decommissioning site.
For calculations a set of the following output parameters divided into two groups is evaluated and discussed:

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.
- Exposure (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 arisen from decommissioning** - these parameters characterize decommissioning option from the dismantled material distribution point of view. This category contains mass distribution of given materials either destined to repositories or released into environment respectively:

- Material released to environment after dismantling – directly released material without application of post-dismantling decontamination.
- Material released to environment after decontamination – dismantled material released after post-dismantling decontamination without melting.
- Material released to environment after melting - dismantled material released after post-dismantling decontamination and consequent melting or direct melting.
- Material destined to near-surface repository – non-releasable material placed in fibre reinforced concrete (FRC) containers for near-surface repository disposal.
- Material destined to deep geological repository - non-releasable material placed in containers for deep geological repository disposal.

Given calculated output parameters are introduced both numerically and graphically in Chapter 8 and in Annexes 4 in more detail way within the PSL structure.

3. Development of Database

Input database needed for calculations in OMEGA code is in principle created by two main types of input data:

- Inventory data – parameters characterizing decommissioned facility.
- Calculation data – parameters characterizing decommissioning process.

Extent of both types of data is large. In the case of inventory data it means to create a database of facility in buildings – floors – rooms – equipment structure with relevant tables. This database includes hundreds of parameters describing physical and radiological parameters of facility e.g. dimensions, area of surfaces, weight, inner volume of equipment, contaminations, dose rates, nuclide vectors, categories of equipment etc.

Calculation database is even larger and consists of huge amount of tables with parameters characterizing decommissioning process with its individual activities. These parameters are heterogeneous; they include e.g. cost unit factors, consumption unit factors, parameters of working groups, time duration parameters, and a lot of other parameters needed for mathematical description of decommissioning process.

In this chapter only most significant and relevant parameters which are used for purposes of FA Facility calculations are mentioned. Developed datasheets with inventory database data and selected calculation data are included as separate Annexes 1 and 2 due to their large extent.

3.1. Facility Inventory Data

For the purpose of decommissioning cost calculations using OMEGA code, an input database of FA Facility at Studsvik has been created. Creation of inventory database is one of the main and the most time-consuming preparatory activities for decommissioning calculations.

The inventory database encompasses all essential data which characterize FA Facility. This database is a baseline for performing any decommissioning calculation of the facility. It includes characterization of physical, material and radiological properties of individual equipment, building structures and rooms within facility. Whole inventory database is structured in logical hierarchical structure building – floors – rooms – equipment. It means that all equipment is assigned to given room, floor and building and is fully traceable within this inventory database structure.

For the purposes of inventory database creation, the SVAFO study [4] was used as the only available source of information. Data which were missing but necessary for purposes of OMEGA calculations were evaluated by calculations (Microshield, Excel) from available indicia in the SVAFO study or by expert judgement. Especially radiological data and some building structure data listed in the previous research project from 2005 within "SVAFO study input data validation" [3].

As it was previously mentioned, database structure consists of database tables of buildings, floors, rooms and equipment. Individual database tables with their content are described in the text below. Complete database is attached in Annexes 1-1 – 1-3.

3.1.1. Database of buildings

Only one building is used for purposes of FA Facility – storage building. This building contains all equipment (technological equipment and building structures) which is being a subject of decommissioning.

3.1.2. Database of floors

FA Facility is formed by main building with three floors: cellar, ground floor and first floor.

Floors have no significant description in inventory database. They are used only for accurate localization of rooms within calculation structure.
Complete database of FA Facility floors implemented into OMEGA code is listed in Annexes 1.

3.1.3. Database of rooms

In this table, all rooms within FA Facility are listed. Each room is characterized by several parameters, such as:

- Identification number of the room.
- Reference to the floor and building.
- Number of the room.
- Name of the room.
- Dimensions of the room.
- Average dose rate inside the room.
- Nuclide vector of dose rate.
- Reference date for dose rate [DD.MM.YYYY].

All of these parameters are required by OMEGA code during development of decommissioning calculation structure and calculation itself.

Rooms are assigned to individual floors:
The cellar floor contains sixteen rooms (room numbers 0.01 – 0.16) 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 – 1.18) 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.

For purposes of calculation, there was also created an extra item for so-called "virtual room" (room number 1.18) in the room database. This room was created for purposes of placement of building structures and building surfaces added to the equipment database – see end of Chapter 3.1.4.

The upper floor contains five rooms (room numbers 2.01 – 2.05) 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.

There was a lot of missing data concerning room dimensions, average dose rates, dose rate nuclide vector and reference date of nuclide vector evaluation. These data have been completed:

Room dimensions were completed on the basis of former site visit (2005) and evaluation based on purpose of the room. Dimensions of storage basins (height and diameter) were transformed to cubic dimensions (width, length, height) whereas the areas of storage basins walls remained unchanged.

Average dose rate in rooms was approximately evaluated from the occurrence of active and inactive equipment in room.

Dose rate nuclide vector is 100 % Co-60 and was evaluated on the basis of SVAFO study, which mentioned only Co-60 as a dominant nuclide for dose rates within FA Facility.

Reference date for dose rate was not known from SVAFO study. We have decided to use year 2001 as a date of dose rate evaluation (the date of SVAFO study issue). This date is used for calculation of dose rate decrease with time.
All rooms are assigned to controlled area since there is no relevant available data on controlled area borders within FA Facility.
Complete database of FA Facility rooms implemented into OMEGA code is listed in Annex 1-2.

3.1.4. Database of equipment

The main portion of input inventory database is created by database of equipment. It comprises technological equipment (pipes, valves, tanks, ventilation, motors etc.) and also building structure equipment (walls, building materials). Both of these types of equipment should be taken into inventory database for calculation of decommissioning parameters. In most cases, individual technological equipment located in the room corresponds to particular database items. Each database item within FA Facility in Studsvik is characterized by relevant parameters as follows:

- Identification number of technological or building equipment – identification of database item within the database.
- Name of technological or building equipment.
- Number of room to which technological or building equipment is assigned.
- Weight of technological or building equipment [kg].
- Inner surface of technological equipment [m^2].
- Outer surface of technological or building equipment [m^2].
- Inner surface contamination of technological equipment [Bq/m^2].
- Outer surface contamination of technological or building equipment [Bq/m^2].
- Nuclide vector of inner surface contamination – represents an average isotopic composition of inner surface contamination source [%].
- Reference date for inner contamination and nuclide vector of inner surface contamination [DD.MM.YYYY].
- Nuclide vector of outer surface contamination – represents an average isotopic composition of outer surface contamination source [%].
- Reference date for outer contamination and nuclide vector of outer surface contamination [DD.MM.YYYY].
- Dose rate nearby technological or building equipment – dose rate 0.5 m from the surface of the technological or building equipment [μGy/h].
- Nuclide vector of dose rate – represent an average isotopic composition of dose rate source [%].
- Reference date for dose rate and nuclide vector of dose rate [DD.MM.YYYY].

- Inner volume of technological equipment – parameter used only for pre-dismantling decontamination by autonomous circuits (not necessary for all equipment).
- Category of technological or building equipment – characterizes type, shape, dimensions and material composition of technological or building equipment. This parameter is used for assignment of default dismantling and demolition procedures.

The Data for characterization of individual equipment are based on SVAFO study information where individual technological equipment is characterized 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 in the SVAFO study are divided into two groups – active and inactive.

Missing and insufficient data, needed for completion of inventory database for OMEGA code purposes, were obtained by modelling calculations or by evaluation or judgement based on experience. The missing or insufficient data were evaluated for these input parameters:

Inner and outer surface of equipment were completed for each of technological or building (only outer surface area) equipment items. Values of areas were calculated on the basis of dimensions published in SVAFO study and on the basis of building structure weight (for building equipment surfaces) and also they were based on expert judgement.

Nuclide vector of inner and outer surface contamination. The SVAFO study database does not include any detail information on nuclide composition of contamination of technological or building equipment. Co-60 is the only mentioned nuclide. However regarding to the history and purpose of facility as an interim storage for spent fuel from older reactors, also Cs-137, Sr-90 and some alpha contaminants can be expected to occur in contamination. It is documented that during the storing of the spent fuel also some fuel assemblies were stored with occurrences of leakages [13]. Therefore, based on the experience from older facilities, and applying the conservative approach (Chapter 2.1) it is proposed to use a tentative nuclide vector which simulates abundance of the above mentioned nuclides in contamination of surfaces. Abundance of Cs-137 is proposed to be around 1/10 of Co-60. Activity of Sr-90 is simulated to be around 1/10 of Cs-137 and activity of alpha contaminants is proposed to be 1/10 of Sr-90. Am-241 and Pu -241 are proposed as typical representatives of alpha contaminants. Nuclide composition and abundance of nuclides on contamination is then as follows:

- Co-60 90,0% half life – 5,27 y.
- Cs-137 8,9% half life – 30,00 y.
- Sr-90 1,0% half life – 28,78 y.
- Am-241 0,05% half life – 432,20 y.
- Pu-239 0,05% half life – 24 110,00 y.

Proposed nuclide vector is used both for inner and outer surfaces.

Nuclide vector of dose rate was chosen the same as for average dose rate in rooms – 100 % Co-60.

Contamination of inner surface. As contaminated equipment only active equipment mentioned in SVAFO study is regarded. There are no data on inner surface contamination for any active equipment within the study. The only relevant data which could be used are based on presumption that "…radioactive contamination of process equipment is expected mainly on the internal area of pipes, tanks and other components and much less on exterior surfaces…" [4]. There is only the remark in the SVAFO study that: "The surface dose rates on pipework in the facility cellar vary between 0.01 and 2mSv/h" [4]. 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.

Radioactive contamination of building structures can be found in significant levels mainly in the restricted areas with components (piping, tanks) or in places with radioactive material for more or less free handling.

For calculation purposes, OMEGA code needs values of contamination for individual active equipment. The only way how to obtain these values without any radiological measurements is to make some approximate simulation of contamination distribution within active components.

Based on this information and requirements, it was decided to simulate distribution of contamination levels for active equipment based on methodology of contamination classes. This simulation is extensive and time-consuming.

Simulation based on this methodology is only provisional and approximate and is being used when no relevant data for better characterization of contamination are available. This approach of contamination classes within active equipment consists of several steps:

1. identification of range (Bq/m^2) in which contamination can vary,
2. partitioning this range into several intervals (four) of contamination level – contamination classes,
3. evaluation of percentage for partitioning of active equipment among these classes. This partitioning should be based on analogy with known contamination distribution from types of systems or equipment with similar contamination composition,
4. inserting of new database items for parts of active equipment based on number of contamination classes and dividing of weight, areas and volumes of original equipment among this new items. Dividing of weight, areas and volumes is based on percentage for partitioning from point 3.

1. Identification of contamination range for active equipment of FA Facility

For stipulation of boundary values of inner surface contamination two available information from SVAFO study were used:

- dose rates on pipework in the facility cellar vary between 0.01 and 2mSv/h,
- estimated conversion factors between dose rates (Sv/h) and specific activity (Bq/kg) for piping (diameters of 50-150 mm) are 3-10 kBq/kg per Sv/h for steel pipework and 20-100 kBq/kg per Sv/h for plastic pipework.

Based on these information, some other approximations and calculations for transforming Bq/kg to Bq/m^2 values for pipeworks was evaluated leading to setting of approximate margins for contamination that can vary from 5.10^6 Bq/m^2 to 1.10^9 Bq/m^2. We have used these margins for inner contamination range of all active components.

2. Partitioning of contamination range into intervals of contamination level

Further step was to determine some intervals for contamination levels within calculated margins. Due to simplicity and tentative character of decommissioning calculations it was decided to create four contamination classes for simulation of contamination distribution within active equipment. Proposed averaged values of contaminations for individual contamination classes are shown in the next table together with dose rates matching to individual contamination classes.

Table 0-1 Contamination classes

Contamination class	Average contamination [Bq/m^2]	Average dose rate [µGy/h]
CC 1	5.00E+6	10
CC 2	5.00E+7	100
CC 3	5.00E+8	1000
CC 4	1.00E+9	2000

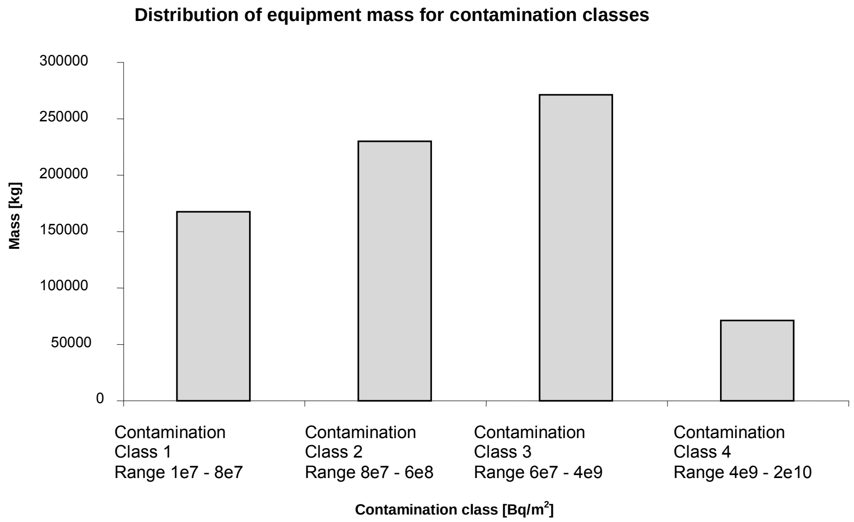
Contamination of classes increases by a factor of 10 except of last contamination class CC4 which is only 5 times higher than CC3 to fit into upper margin of contamination range (1.10^9 Bq/m^2).

3. Evaluation of percentage for partitioning of active equipment among contamination classes

Mass distribution of primary circuit pipes in NPP A-1, Jaslovske Bohunice, Slovakia, was used for this percentage evaluation. There are two reasons for using A-1 primary circuit piping data:

1. Nuclide composition of A-1 NPP contamination (inner surfaces of primary piping) is similar to the nuclide composition proposed for FA Facility (abundance of Co-60, Cs-137, Sr-90, alpha).
2. Good availability of contamination and weight data based on real measurements from A-1 NPP primary circuit piping characterization.
3. Contamination range of A-1 NPP primary circuit pipes was divided among four contamination classes in analogy with contamination classes system used in FA Facility (see CC1 - CC4 in Table 3 -1). Mass of all equipment of primary circuit was then distributed among these classes according to intervals of contamination. The result of this distribution for four contamination classes is shown on the following figure:

Figure 0-3 Distribution of mass of A-1 NPP primary circuit pipes among four contamination classes



The ratio of equipment mass in individual contamination classes displayed on

Figure 0-3 to total mass of primary circuit piping was calculated. Resultant percentage was as follows:

- 23 % of original equipment mass for contamination class 1,
- 31 % of original equipment mass for contamination class 2,
- 37 % of original equipment mass for contamination class 3,
- 9 % of original equipment mass for contamination class 4.

4. Creating new database items according to contamination classes for active equipment

Every active equipment from FA Facility was partitioned into four parts (according to amount of contamination classes CC1 - CC4 from Table 0-1). The mass and area of inner/outer surfaces of original equipment was divided among these parts by percentage stipulated above. Each part of equipment has assigned appropriate contamination level of inner surface (Bq/m^2) based on its contamination class.

That means every original active equipment was partitioned into four new parts each with its own mass, surfaces, and inner contamination level based on contamination class. These parts were inserted into inventory database of equipment and original equipment was removed from the database. Therefore the number of database items of technological and buildings equipment is higher in comparison to the list of equipment in SVAFO study.

Contamination of outer surface for active components was evaluated based on SVAFO study, which mentioned that surfaces in the hall had a yellow classification, which implied activities of between 40 and 400 kBq/m^2 (β, γ) and between 4 and 40 kBq/m^2 (α).

Based on this information we conservatively used 4.10^5 Bq/m^2 as a value for outer surface contamination for all active technological equipment and contamination of building equipment (surfaces) in the database.

Reference dates for inner, outer contamination and dose rate. We used the same date as in the case of room dose rate - 2001.

Categories of equipment. The categorization of equipment implemented in OMEGA code in compliance with information about categories used in SVAFO study was used. Based on this approach, 34 categories for technological equipment and 9 categories for building equipment were used. The list of used equipment categories is shown in the next tables:

Table 0-2 Table of technological equipment categories used for equipment in the inventory database

Type of equipment category	Category of equipment	Number of database items
Pipes	Piping (PE, PP ..), D25 < diameter <= D100 mm	60
	Piping (SS), D25 < diameter <= D100 mm	78
	Piping (CS), diameter =< D25 mm	32
	Piping (CS), D25 < diameter <= D100 mm	47
	Colour metals pipes	43
Valves	Valves (CS), mass <= 50 kg	19
Pumps	Pumps (CS), mass <= 50 kg	20

Type of equipment category	Category of equipment	Number of database items
	Pumps (CS), mass > 50 kg, at least one dimension > 1m	1
Motors	Electric motors, mass <= 50 kg	4
Tanks and containers	Tanks and containers (CS), diameter < D 1 m, thickness of wall <= 20 mm	26
	Tanks and containers (CS), diameter >= D 1 m, typical wall thickness 12 mm	14
	Sampling boxes (CS)	2
Heat exchangers	Heat exchangers (CS), diameter <= 1m, typical wall thickness 20 mm	7
Air condition equipment	Air conditioning components - piping (CS), cross section < 0,16 m^2	40
	Air conditioning systems, filter casings (CS), dimension <= 1m	4
Ventilators	Ventilators (CS), mass <= 50 kg	1
	Ventilators (CS), mass > 50 kg, at least one dimension > 1m	8
Hoisting equipment	Hoisting equipment (CS), electrical tackles	1
	Hoisting equipment (CS), cranes	4
Electric and control equipment	General electric equipment, (CS) mass <= 50 kg	9
	General electric equipment, (CS) mass > 50 kg	8
	Non-portable small equipment & instruments (CS), mass <= 50kg	2
	Non-portable small equipment & instruments (CS), mass > 50kg	1
Electric cables	Electrical cables & conductors; (Cu), 1 kV power cables	11
	Control & low-voltage cables (Cu)	2
Thermal insulation	Thermal insulations, non-metal covering	56
Casing and linings	Casing of technological equipment (CS), thickness < 100 mm	2
	Stainless steel linings, (SS)	1
Technological steel constructions	Steel constructions, (CS), hangings of piping, general hangings	5
	Steel constructions, (CS), platforms and stages	1
	Steel constructions, (CS), stairs, ladders, railings	1
	Steel constructions, (CS), dismantling appliances	1
Others equipment	Piece components (CS), mass <= 200 kg	19
	Other general equipment	3
	Gulleys, (SS)	6
Total		**539**

Table 0-3 Table of building equipment categories used for equipment in the inventory database

	Technological equipment	
	Category of equipment	**Number of database items**
Buildings materials	Masonry	1
	Contaminated concrete	1
	Steel skeletons, (CS)	2
	Other building construction	1
	Reinforced concrete, thickness <= 400 mm	2
	Building structure - carbon steel	1
Building surface for decontamination	Building surface (cement screeding, epoxid paint)	1
	Building surface (epoxid system)	1
	Building surface (building surfaces with low adhesion)	1
Total		**11**

There were also added some building equipment for purposes of calculation of demolition and decontamination of building surfaces in OMEGA code as follows:

- Items characterizing weight of building materials for demolition of building structures.
- Weights of items needed for demolition of building structures (masonry, contaminated concrete, steel skeletons…) were adopted from SVAFO study (Appendix 6, 8 a 9 in [4]) or were calculated on the basis of known volumes and specific weight materials also given in SVAFO study.
- Items characterizing surfaces of building materials for decontamination of building surfaces.
  - Surfaces of storage basins – area of surfaces was calculated on the basis of their dimensions (expected mechanical decontamination).
  - Surfaces of floors in active rooms – area of surfaces was calculated by summation of floor areas of rooms with active components (expected mechanical decontamination).
  - Surfaces of walls (1 m height) in active rooms - area of surfaces was calculated from dimensions of rooms with active equipment conservatively to height of 1m (expected chemical decontamination).

This building equipment was assigned to virtual room, created in database of rooms for this purpose – see Chapter 3.1.3.

The complete inventory database used for calculation including all databases (floors, rooms, equipment) and items within these databases is listed in Annexes 1-1 – 1-3.

3.2. Calculation Data

One part of input data is represented by inventory database mentioned in previous text. The second part of input data are calculation data. These data describe activities which are carried out during decommissioning process.

In OMEGA code, individual decommissioning activities are described by mathematical models. These models are represented by calculation procedures. Calculation procedures need for their run a set of calculation parameters which characterise and quantify input parameters of procedure. That includes a broad spectrum of parameters: Parameters describing features of activity such as capacity of decommissioning technology or technique, consumption of various consumables and materials used, working group composition (amount of workers and their professions), costs parameters (wages of workers, costs unit factors of consumed media and materials), and other parameters.

For purposes of decommissioning re-calculations for FA Facility, updated parameters implemented in OMEGA code were used. Values of these parameters come out either from Swedish available data (wages) or from international available data (cost unit factors of consumables, capacities, consumptions) or from Slovak data (work groups, waste management scenario data, Wages are the most important data, influencing decommissioning costs, as well as manpower unit data.

Main calculation parameters used within OMEGA code are described in this chapter. For better orientation, data are divided into three groups according to their character.

1. General calculation data - data concerning cost unit factors and other overall data.
2. Calculation data for technological procedures – these data include technological parameters of decommissioning procedures and parameters of working groups used for these procedures.
3. Specific calculation data – these data include parameters of preparatory, support and management activities which have time dependent character (duration of procedure, working group for procedure).

Due to large extent of input calculation parameters all data sheets containing individual data tables are attached in Annexes 2.

3.2.1. General calculation data

This group of calculation data encompasses mainly cost unit factors. For the purposes of re-calculation Swedish data for labour cost units are used and available international data from international market are used for selected most important cost unit factors of consumables, substances and materials. Database parameters are listed in Annex 2-1.

First portion of cost unit factors encompasses labour cost unit factors of individual professions (see Chapter 3.2.2) used in working groups within calculation. For purposes of calculation, values of labour cost unit factors are expressed in EUR per manhour. Total sum of social security contributions, insurance, social charges and other charges paid by the company are included within these labour cost unit factors.

Second portion of cost unit factors represents selected cost unit factors for consumables, substances and materials used by technological procedures within calculation. These cost unit factors are collected from parameters of individual procedures to one common table. Values are expressed in EUR per unit of consummated material.

Other general parameters used in calculation are shown in third table of Annex 2-1. This table includes common used parameters such as work days per year, work hours per shift, dose rate of background in facility and some others.

3.2.2. Calculation data for technological procedures

These input data represent a major portion of all calculation data, characterise and quantitatively describe individual technological decommissioning activities from pre-dismantling decontamination through dismantling, waste management up to disposal of waste packages. Extend of technological procedures included in decommissioning calculation for FA Facility is based on Chapter 4 were individual activities are listed.

Calculation parameters of individual decommissioning procedures are used in combination with parameters from inventory database for calculation of output parameters. Calculation data for technological procedures include technical/economical parameters and working group parameters.

Technical and economical parameters characterise technological features of procedure. The main used parameters are:

- manpower unit factors (for hands on activities and techniques),
- capacities of equipment (for machines and technological lines),
- consumption unit factors – consumption rates of electricity, steam, fuel oil, air, chemical substances, working tools and equipment etc.,
- cost unit factors – prices for electricity, steam, fuel oil, air, chemical substances, working tools and equipment etc. – main cost unit factors are selected in general calculation data mentioned above.

Working group parameters includes assignment of working group to individual activities. Working groups consist of individual universal professions. Each profession in working group has assigned number of workers. There are seven universal profession types used for characterization of working groups:

- manager (average personnel on the management level),
- senior engineer (experienced graduated engineer, more than 10 years of experience in the field),
- engineer (standard graduated engineer),
- operator (qualified operator in relevant branch with secondary school education),
- administrative worker (secondary school education),
- skilled worker (qualified craftsman),
- auxiliary worker (semi skilled).

Individual working groups have also assigned a structure of non-effective working time fractions during carrying out work within individual working group. These non-effective working time fractions are by-products of effective time needed for decommissioning activity and these are time consuming, e.g.: entrance of workers to controlled area, breaks in work, moving of personnel during working time within controlled area, exit from controlled area, etc. In calculations, OMEGA default values for non-productive time fractions for all workgroups are used.

Values of used parameters within this database were obtained from various sources: price catalogues for evaluation of costs in industrial sectors in Slovakia, from operational experience of technological lines at A-1 NPP and maintenance of V-1 and V-2 NPP, international catalogues and prospects of producers of dismantling and demolition equipment. In addition, a lot of useful parameters were evaluated within cooperation with Japan specialists in the frame of cooperation on A-1 NPP decommissioning.

Data sheets of calculation data for technological procedures are divided into several parts according to the type of calculation technological procedures. In the beginning of each part there is a list of included procedures and also table of non-productive working time fractions for working groups. There is a table of parameters with values listed for each calculation technological procedure together with table for assigned work group.

Individual datasheets of calculation data for technological procedures with parameters are attached in Annex 2-2. Number of parameters used for individual procedures is very extensive, owing to simplify parameters review only main and most important parameters are listed in datasheets. Data listed in datasheets are mentioned within colour legend. Legend distinguishes most important or specialized parameters by individual colours.

3.2.3. Specific calculation data

These data are used for activities, which have time dependent character. These activities do not have technological character but they are an important part of decommissioning process. They are connected with preparatory activities (decommissioning planning, preparation of documentation, etc.), management and decommissioning support activities (management unit, security and safety during decommissioning, etc.).

Main parameter for this type of procedures is time of duration, which determines how long a particular activity is carried out during the decommissioning process. Then a composition of working group is necessary – professions and numbers of workers in professions, involved in given time dependent activity. Based on this data and parameters of professions wages data (included in general data), cost for workforce can be calculated. Investments and expenses are another type of costs which can are used as specific data within the time dependent procedures. Fixed costs represent investment costs, for example in the case of procurement of some equipment, devices or mechanisms. Expenses are connected costs expressing usage of outsourced services or works. It has to be stressed that these costs are subject to local conditions and depend highly on suppliers rates based on individual contracts conditions.

Table with specific calculation data for individual selected time dependent procedures is attached in Annex 2-3.

4. Definition of Activities

This chapter contains review of procedures representing individual decommissioning activities which are implemented within OMEGA code. Not all of these procedures are used within FA Facility re-calculation, (they can be used for other facilities with more various radiological and technological inventory), but they are mentioned owing to complexity of overview of implemented procedures in OMEGA code.

4.1. Methods for Definition of Decommissioning Activities

One of the main features of the OMEGA code is the implementation of the standardised list of decommissioning activities [7]. The standardised list includes all activities that could be identified in any decommissioning project. From this point of view, the definition of extent of decommissioning activities involved in the given decommissioning project, means the methods for selecting of decommissioning activities, relevant for the given project. The OMEGA code involves a set of standardised templates of decommissioning activities, which include segments for basic types decommissioning activities:

- Inventory-dependent activities, related to the extent of “hands-on” work like dismantling, decontamination , etc.
- Period-dependent activities, proportional to duration of individual decommissioning activities/phases.
- Definition of fixed costs (costs special items which can neither be assigned to inventory-dependent activities nor to period-dependent activities.

For the first type of decommissioning activities, the segments in the template are available which corresponds to facility structure of buildings – floors – rooms/cells - inventory items in rooms/cells. For the second and the third type of decommissioning activity, the universal segments were developed, which can be applied in the given decommissioning project by implementing the procedure described below.

The user can configure the executive standardised calculation structure in three steps using the templates which facilitates significantly the work of the user. The base for this work is the general standardised template which covers the decommissioning activities as defined in [7]. In the first step the user can develop the master template which is specific for a type of a nuclear facility. In the second step the user can adapt the selected master template to the standardised structure specific to the decommissioning option to be calculated. In this step the user can define as much calculation options as required for the evaluation within the decommissioning project. The option specific standardised structure of decommissioning activities involves also the prescriptions for generation of lower levels of calculation items, for allocating the calculation procedures and definition of calculation sequence.

The third step is the automatic generation of the executive standardised calculation structure. The typical feature of this structure is that it has the hierarchical structure of the buildings – floors – rooms/cells – inventory items in the room/cell in selected sections of the standardised structure, as required in basic definition of decommissioning activities in [2]. The generated structure contains also input calculation data with default values. After the generation, the user can review/edit the generated calculated structure and the generated default values of the calculation data.

The generated calculation structure involves all decommissioning activities as defined in [7] and the definition of the extent of calculation is defined by the user by clicking in the individual calculation items. The procedure of generating the standardised calculation structure is presented in Chapter 6.

The decommissioning activities presented in Chapters 4.2 to 4.4 are the activities of the “inventory dependent type” and for these activities the relevant segments in executive calculation structure were generated based on the FA Facility inventory database and on the standardised template developed specially for the FA Facility, The procedure is described in the Chapter 6. These decommissioning activities are specific for the FA Facility.

The decommissioning activities presented in the Chapter 4.5 are activities planning activities for preparing the decommissioning project and general management and supporting activities during the execution of the project. These are activities of the “period dependent type” and “fixed cost”. For calculation of parameters for these activities, the “static” segments of the executive calculation structure are used.

4.2. Dismantling Activities

According to PSL classification, dismantling activities cover pre-dismantling decontamination of technological equipment, dismantling technology itself including preparatory and finishing activities, decontamination of building surfaces, final building radiation survey and post-dismantling decontamination of dismantled equipment. These activities are described in further text with regard to FA Facility decommissioning.

4.2.1. Pre-dismantling decontamination

Pre-dismantling decontamination is being used in calculation due to decrease of dose rates from dismantled equipment or decrease of possible creation of aerosols during dismantling operations. Based on SVAFO study information there is an assumption of internal contamination of piping and other equipment, therefore a pre-dismantling decontamination by autonomous circuits for inner surfaces of equipment was applied in calculations but for FA Facility decommissioning calculations pre-dismantling decontamination is not considered. Deeper analysis of technological systems should be carried out to identify reference of individual equipment (pipes, tanks, pumps, valves) to individual technological systems, to be able to arrange equipment into potential decontamination loops in proper manner.

4.2.2. Dismantling procedures

Dismantling procedures involve the biggest portion of calculation. These procedures describe activities of dismantling (removal) of technological equipment from rooms. Dismantling is carried out in controlled area (active rooms) or outside the controlled area (inactive rooms). Dismantling in controlled area, in common, demands higher manpower than outside the controlled area.

There are three types of procedures during dismantling used in calculation:

- preparatory procedures before dismantling,
- dismantling procedures,
- finishing procedures after dismantling.

Preparatory procedures before dismantling

These procedures describe and calculate a set of activities carried out before dismantling itself and they are carried out for whole individual rooms (room oriented approach). Choice of individual preparatory procedures within particular room is optional.

- **Survey of radiological situation** – mapping of radiological situation in room directly before dismantling.
- **Covering of floor by protective foil** – covering of contamination protective foil on the floor of the room.
- **Installation of scaffolding** – assembly of scaffolding needed for dismantling of equipment placed in heights.
- **Installation of temporary ventilation** – installation and testing of local mobile ventilation with HEPA filters in the room which will be used during dismantling.
- **Installation of temporary electric and other media connections** – installation and testing of connections for electricity and other media (air, water, etc.) supply in the room.
- **Disconnection and revision of dismantled technological equipment** – safe removal and closing of any connections of dismantled equipment to other systems (media, electricity) before dismantling in room.
- **Marking of cuts and areas** – drawing of lines for cuts which determines parts of equipment and guide personnel during dismantling.
- **Delivery of working tools and equipment** – transport of working tools and equipment into room being segmented before dismantling.
- **Preparation of working tools and devices** – activities connected with preparation, check setting and adjusting of dismantling tools and devices in room.
- **Preparation of transport containers** - delivery and placement of transport containers for dismantled material in room.
- **Installation of protective tent** – assembly of foil covered protective tent against spreading of potential aerosols during dismantling.
- **Working group instructions** – preparation and instruction of activities, cooperation and safety for working group personnel before dismantling in room.

These preparation activities are carried out before dismantling in active rooms (inside the controlled area). The set of preparation activities prior dismantling outside the controlled area (inactive rooms) is similar but activities relevant only for controlled area are omitted (survey of radiological situation, covering of floor by protective foil, installation of temporary air-conditioning, installation of protective tent).

For the purpose of tentative decommissioning calculations by OMEGA code for FA Facility using the whole set of preparatory procedures for active rooms as well as for inactive rooms is used.

Dismantling procedures

These procedures represent dismantling itself. Dismantling procedures can be used both for active (inside the controlled area) or non-active equipment (outside the controlled are). Following techniques have been selected for the purpose of dismantling calculation [14], [15]:

- Dismantling by hydraulic shears.
- Dismantling by oxygen-acetylene set.
- Dismantling by plasma set.
- Dismantling by circular saw.

- Dismantling by hand tools (wrenches, etc.) .

Dismantling by hydraulic shears is used especially for cutting of low diameter metal elements (pipelines, plates, ventilation hoists, instrument panels, electric network installations, cables) which are made of steel, colour metals, (copper and its alloys, aluminium), plastics (PE pipes) or other materials.

Dismantling by oxygen-acetylene set is frequently used for cutting of non-active steel materials. This technique is applicable for cutting of steel tanks, structural and bearing parts of equipment, ventilation parts, cranes and other components, depending on their shape and thickness. Considerable amount of aerosols are produced during application of this technique and released into the workspace. That is why it is proposed just for non-active part of the equipment.

Dismantling by plasma set is applicable for cutting of any metallic materials using plasma burner. This technique is used especially for dismantling of various stainless steel equipment inside the controlled area. Aerosols are produced during cutting which have to be removed by ventilation. Dismantling by plasma set is used mainly for dismantling of heat exchangers, tanks, air conditioning pipes, ventilators, valves, steel linings and others.

Dismantling by circular saw is a cutting technique frequently used for dismantling of technology equipment of longitudinal shape, such as pipelines, rods, bearers and other parts made of steel, colour metals, plastics. It is applicable especially for dismantling inside the controlled area due to low production of aerosols.

Dismantling by hand tools is a technique used for dismantling of technology equipment by means of hand instruments (screwdrivers, wrenches, various types of jigs). This manual method is the most frequently used especially in case of assumed re-using of dismantled components (electric motors, compressors, pumps, valves, electric equipment, diagnostic devices.

A number of technology categories were assigned to each of mentioned dismantling techniques. The combination matrix of individual material categories and dismantling techniques was elaborated for the purpose of FA Facility calculation, as shown in the Figure 0-4. Particular combinations used within the calculation procedure are marked by full bullets. This combinations are based on choosing of most suitable and applicable dismantling techniques for given categories of equipment regarding to radioactive conditions. For completeness, other alternative combinations possible in OMEGA are added marked by circles. Complete list of the selected material categories is given in the Chapter 3 of this report. A list of material categories given in the following table is reduced due to comprehensibility. Combinations mentioned below are valid for dismantling in the controlled area as well as for the non-controlled area.

Figure 0-4 Combination of used technological equipment categories and available dismantling procedures.

Note:

used combination ●

alternative combination ○

		Dismantling (manual) by hydraulic shears in CA	Dismantling (manual) by oxygen-acetylene set in CA	Dismantling (manual) by plasma set in CA	Dismantling (manual) by circular saw in CA	Dismantling (manual) by hand tools (wrenches, etc.) in CA
1	Piping (CS), various diameters	●	●	●	●	
2	Piping (SS), various diameters	○		●	●	
3	Piping (PE, PP ..), various diameter	●			○	
4	Air conditioning components - piping (CS), various cross sections [m^2]	●	●	●		●
5	Electrical cables & conductors; (Cu, Al)	●				●
6	General electric equipment, various mass		●	○		●
7	Heat exchangers (CS) , various dimensions [m]		●	○		
8	Pumps (CS), various mass [kg]		●	○		●
9	Piece components (CS), various mass [kg]		●	●	●	●
10	Non-portable small equipment & instruments (CS), various mass [kg]	○	●	○		●
11	Valves (CS), various mass [kg]		●	○		●
12	Ventilators (CS), various mass [kg]		●			○
13	Thermal insulations	●				●
14	Sampling boxes (CS)		●			●
15	Steel constructions, (CS)		●	●	●	●
16	Tanks and containers (CS), various diameters [m], various thickness of wall [mm]		●	●		
17	Casing of technological euipment (CS), various thickness [mm]		○	●	○	○
18	Hoisting equipment (CS)		●	●		●
19	Stainless steel linings (SS)	○		●		
20	Electric motors, various mass [kg]		○			●
21	Ventilators (CS), various mass [kg]		●			●
22	Other general equipment		●	○		●

Finishing procedures after dismantling

Similarly to preparation activities prior dismantling, there is a set of finishing activities, represented by calculation procedures, used after dismantling of equipment in room. Choice of individual finishing procedures within particular room is optional.

- **Removal of scaffolding** – de-installing and removal of scaffolding after dismantling.
- **Removal of protective foil** – fixing dust and dismantling residual materials particles on the foil surface, rolling and packing of protective foil from floor of the room.
- **Removal of temporary ventilation** – de-installation and removal of temporary mobile ventilation from room.
- **Removal of temporary electric and other media connections** – de-installation and removal of connections for electricity and other media (air, water, etc.) supply in the room.
- **Removal of working tools and devices** - transport of working tools and devices out of room after dismantling to designated place.
- **Removal of protective tent** – de-installation of foil protective tent after dismantling.
- **Removal of transport containers** - transport of containers with dismantled material out of the room to designated place.

- **Cleaning of room** – final cleaning and removal of any remains after dismantling of equipment in the room.

These finishing activities are carried out after dismantling in active rooms (inside the controlled area). The set of finishing activities after dismantling outside the controlled area (normal inactive rooms) is similar but activities relevant only for controlled area are omitted (removal of protective foil, removal of temporary air-conditioning, removal of protective tent).

Individual preparation and finishing activities were selected room by room with regards to radiological and technological properties of individual room and its equipment. Matrix of selected preparatory and finishing activities for FA Facility by rooms is showed in Annex 2-4. Criterions for using of given preparatory and finishing activity for individual room are as follows:

Preparatory activities

- Radiological survey prior dismantling.
  - Radiological survey has been used for all rooms. This is conservative approach due to old technological facility where possible unknown sources of contamination/dose rate can occur within rooms and history records can be unreliable.
- Covering of floor by plastic foil, Installation of temporary air-conditioning, Installation of protective tent.
  - These preparation activities prior dismantling were used in the case when room contains at least 10 contaminated equipment.
- Installation of scaffolding.
  - This preparation activity prior dismantling was used if there are supposed some equipment which is inaccessible from the floor level.
- Installation of temporary electric connection, Marking of cuts and surfaces, Delivery of working tools and equipment, Disconnection and revision of decommissioned technological equipment, Preparation of working tools and equipment.
  - Activities have been used for all rooms with number of dismantled equipment ≥ 10 pcs.
- Preparation of transport containers.
  - Activity has been used for all rooms with number of dismantled equipment ≥ 5 pcs.
- Working group instructions.

This activity is used for all rooms due to safety reasons.

Finishing of dismantling.

- Removal of temporary air-conditioning, Dismantling and removal of scaffolding, Removal of temporary electric connection, Removal of protective tent, Removal of working tools and equipment, Removal of transport containers.
  - Activities have been used if corresponding preparation activities had been realized.
- Cleaning of room
  - Activity has been used for all rooms.

4.2.3. Decontamination of building surfaces procedures

Decontamination of building surfaces is also taken into account in calculations for FA Facility. There are used decontamination procedures representing mechanical and chemical decontamination of building surfaces [14], [15]. Decontamination is supposed for rooms with presence of active components. Conservatively, there is calculated mechanical decontamination for whole floors and chemical decontamination of walls up to height of 1m in these rooms and also mechanical decontamination of whole surface of storage basins.

There are three types of procedures during decontamination of building surfaces used in calculation:

- preparatory procedures prior decontamination of building surfaces,
- decontamination of building surfaces procedures,
- finishing procedures after decontamination of building surfaces.

Preparatory procedures prior decontamination of building surfaces

System of procedures is the same as in the case of preparatory activities prior dismantling and includes the following procedures:

- Survey of radiological situation.
- Covering of floor by protective foil.
- Installation of scaffolding.
- Installation of temporary air-conditioning.
- Installation of temporary electric and other media connections room.
- Marking of decontaminated areas.
- Delivery of working tools and equipment.
- Preparation of working tools and equipment.
- Preparation of transport containers.
- Installation of protective tent.
- Working group instructions.

Decontamination of building surfaces procedures

Chemical decontamination by foam application, vacuum cleaning and washing includes application of decontamination foam or reagent on decontaminated surfaces by application machine, action of applied foam on surface, vacuum cleaning of applied foam and final washing by water. This procedure is used in calculation for decontamination of walls (1 m height) in rooms with active components.

Mechanical decontamination by shaving represents decontamination by machine or hand tool equipped with grinding disk – shaver, which mechanically removes surface layer of building surfaces. Technique is suitable for building surfaces with suspicion of contamination penetrated into deeper layers of building material.

This procedure is in calculation used for decontamination of storage basins surfaces and decontamination of floors in rooms with active equipment.

Finishing procedures after decontamination of building surfaces

Set of these procedures is very similar as for the finishing of dismantling procedures. It includes procedures as follows:

- Removal of working tools and equipment.
- Removal of scaffolding.
- Removal of protective foil.
- Removal of temporary air-conditioning.
- Removal of temporary electric and other media.
- Removal of protective tent.
- Removal of transport containers.

Preparation and finishing activities for building surfaces decontamination have been used for all rooms with contaminated equipment on floors and walls to high 1 m from floor.

4.2.4. Final building RA-survey procedures

The level of residual contamination will be monitored after completion of building surfaces decontamination and prior to release of building object from control [14], [15].
Final building surfaces RA-survey consists of three partial activities:

- Preparation activities for radiation monitoring of building surfaces.
- Radiation monitoring of building surfaces.
- Finishing activities after decontamination of building surfaces.

Set of preparation activities comprises following procedures in calculation:

- Installation of scaffolding.
- Marking of surfaces.
- Preparation of working tools and equipment.
- Preparation of RA-survey, calibration.

Radiation monitoring of building surfaces

This procedure represents radiation monitoring of building surfaces (walls, floors) prior releasing of building from regulatory control. Radiation monitoring is carried out by workers equipped with handheld monitors in rooms where active equipment are situated and contamination of surfaces is supposed to be. Monitoring is made for both wall and floor surfaces.

Set of finishing activities after decontamination of building surfaces includes next procedures:

- Removal of scaffolding.
- Removal of equipment.
- Release of the room.

Preparation and finishing activities of radiological survey have been used for all rooms in FA Facility.

4.2.5. Post-dismantling decontamination of technological equipment

Post-dismantling decontamination is used to obtain larger amount of material for unconditional or conditional release or decreasing of material amount destined to repository disposal.

The chemical post-dismantling decontamination by means of ultrasound is considered in calculations. Dismantled material is immersed into the tank filled with chemical decontamination solution and its contaminated surface layer is removed by means of ultrasound action. Afterwards, material is transferred into rinsing tank where it is rinsed by detergent and demineralized water.

For FA Facility decommissioning calculations, wet bath post-dismantling decontamination equipment for iron/steel radwaste is considered in radioactive waste treatment scenario as stated in Chapter 2.3.

4.3. Waste Management

For the purpose of decommissioning re-calculations for FA Facility in Studsvik a set of radioactive and non-radioactive waste management technologies are considered. Short characteristics of each waste management technology used in OMEGA decommissioning calculations are given below. Described technologies are commonly used for waste treatment from decommissioning. For further specification of decommissioning calculations for FA Facility to Swedish conditions it would be necessary to specify waste management technologies available at Studsvik site together with their parameters as well as the final waste package forms and their disposal routes.

4.3.1. Radioactive waste management

Treatment and conditioning of radioactive waste (RAW) consists of a lot of technological procedures. The objective of these procedures is to reduce the volume of RAW, decrease the mobility of radionuclides and create a material matrix suitable to dispose of the waste in repository.

There is a variety of RAW generated during activities of dismantling and decontaminations. Following technologies for material treatment and conditioning in OMEGA code calculations are used:

A) Technological methods for treatment of solid RAW:

- fragmentation of metals and cables,
- compaction (low and high pressure) of incombustible waste,
- incineration of combustible waste,
- melting of metals,
- cementation of fragmented RAW into drums.

B) Technological methods for treatment of liquid RAW:

- evaporation,
- bituminization,
- cementation,
- vitrification.

C) Technological method for packaging of RAW to final product - FRC

Conditioned RAW (drums, pellets) is placed into the FRC containers and then they are grouted by cement mixture in disposal containers.
Following Chapters (4.3.1.1, 4.3.1.2, 4.3.1.3) contain a short description of treatment activities using by OMEGA code for creation of waste management scenarios. However whole waste management scenarios for metal, non-metal and liquid RAW as well as RAW production in decommissioning process are described in Chapter 5.

4.3.1.1. Technological methods for treatment of solid radwaste

Fragmentation of metals with radioactivity up to 3kBq/cm^2

This workplace includes fragmentation by air plasma cutting, hydraulic shears and circular saws. Dismantled material is transported to the fragmentation workplace in standardized ISO containers (1,6 x 1,2 x 1,4 m) with weight capacity 1,5 t. Material is fragmented to pieces with maximal dimensions up to 200 mm and filled into 200 l drums. Maximal allowed dose rate is 2 mGy/h at the surface of a drum. Capacity of fragmentation is considered to about 78 kg/h.

Fragmentation of metals with radioactivity over 3kBq/cm^2

This fragmentation workplace is remotely controlled due to higher radioactivity of dismantled material. The dismantled material is cut by hydraulic shears. Material is fragmented into 200 l drums. Capacity of fragmentation is considered to about 31 kg/h.

Low-pressure compaction

Low pressure compactor is hydraulic equipment designed for incombustible solid material compaction (PVC, glass, isolation glass wool, brash metal material). The RAW is compacted directly in 200 l drum. Drums with compacted RAW are intended for high-pressure compaction. Considered capacity of low-pressure compaction is 1,6 m^3/h.

High-pressure compaction

High-pressure compactor is designed for drums with low-pressure compacted materials, drums with small pieces of fragmented metals or debris. In this process the whole drum is compacted. Dimensions of output product depend on compressibility of compacted waste. That can be pellets or only partially compressed drums. These products are destined to final cementation into concrete disposal containers for near surface repository. Capacity of low-pressure compaction is 3 drums/h with average weight of drum 330 kg.

Incineration

Combustible solid wastes packed in bags (3-10 kg) and transported in 200 l drums, processed in the incinerator. Incineration of a burnable liquid waste (oils, lubricant and grease) is also possible. Washing liquids for exhaust gases cleaning are generated as a secondary RAW. These can be used as an active cement grout in cementation process. Generated ash is solidified in cement matrix. We suppose capacity 50 kg/h of input RAW with volume reduction factor around 15 and generation of 200 l of washing liquid per 1t of RAW.

Melting of metal RAW

Melting is used for, in combination with post-dismantling decontamination, increasing of amount of material for conditional and unconditional release. It means that melting is not intended for volume reduction of non releasable materials.

Individual radionuclides can have different behaviour in the process of melting. Some migrate from metal (or its surface) to exhaust gases or slag, some migrate only a little and mostly stay in metal volume. This behaviour of radionuclides is also taken into account in calculation. Supposed capacity of melting furnace is 3 000 kg/shift.

Cementation of solid RAW into drums

This cementation facility is designed for solid materials which radioactivity level does not allow high-pressure compaction. Fragmented material is grouted with cement mixture directly in drum. Capacity of drum cementation is 3,6 drum/h.

4.3.1.2. Technological methods for treatment of liquid waste

Evaporation and bituminization

Bituminization facility is intended for processing and fixation of liquid concentrates, sludge or used ion exchangers. Firstly, waste waters are concentrated by evaporator with natural circulation. Thicken liquid is consequently fixed into bitumen by rotary evaporator and filled into 200 l drums. Spent ion exchangers and condensate are generated as a secondary waste during the process of bituminization. Limit salinity of evaporated concentrates is intended to be about 180 kg/m^3. Capacity of bituminization facility is 0,27 drum of bitumen product per hour.

Secondary liquid RAW generated from decontamination activities in FA Facility is in calculations assumed either to be bituminised or used as for preparing an active cement grout in cementation process of final waste packages – FRC containers.

Vitrification

Liquid RAW with high level of overall radioactivity and especially with significant alpha radioactivity are treated by vitrification. Liquid RAW is concentrated in evaporator and generated concentrate is mixed with glass frit, dried and incorporated into glass matrix during melting of glass frit. Glass product is filled into metal shells with 7 liters volume and they are destined for cementing into containers for deep geological disposal. Assumed capacity of vitrification line is 0,002 m^3/h.

Vitrification is the very special procedure belonging to treatment of highly contaminated liquids however in case of FA Facility it is not used for treatment of generated secondary radioactive liquids from decontamination activities.

4.3.1.3. Technological method for conditioning of RAW to the repository

Final cementation into FRC containers destined to near surface repository

The parameters of final conditioning and disposal of RAW are used as for Slovak conditions because the parameters of Swedish RAW repository or final disposal packages are not known in details.

Cementation into FRC containers is used for final disposal of RAW that cannot be released and its radioactivity enables disposal at surface repository.
The FRC (fibre reinforced concrete) container is a cubic container designed for disposal of RAW at near surface repository. It is made of concrete reinforced by metal fibres (mixed together with concrete). Its inner volume is 3 m^3 and payload 10 t.

There are solid radioactive wastes placed into FRC containers such as high-pressure compaction products, drums filled with bitumen, cement product or pressured RAW, stand alone RAW (e.g. debris). These solid wastes are consequently fixed in the FRC container by cementation mixture grouting.
Capacity of cementation is 1 FRC container per day.

Final cementation into FRC containers destined to deep geological repository

Radioactive waste which can't be disposed at near surface repository has to be cemented into containers and destined to future deep geological repository. Disposal at deep geological repository is needed mainly for high alpha level contaminated materials or for high level activated reactor core materials.

Pieces of a high level activated or contaminated material and products of vitrification are put into containers and consequently grouted by cement mixture.

Payload of container is 4,5 t and capacity of cementation is 1 container per day.

4.3.2. Non-radioactive waste management

There is significant production of non-radioactive waste in process of decommissioning. These wastes are represented by two groups of materials:

1. Materials from decommissioning in controlled area of the FA Facility building that are after sorting, decontamination (if it is needed) and radioactivity measurement classified as materials releasable into environment:
   - some metal or non-ferrous materials from dismantling or after subsequent decontamination process if necessary,
   - building materials from demolition of buildings and,
   - ingots after melting process (if their radioactivity after melting is lower than the level of radioactive limits for release into environment).
2. Materials from decommissioning outside the controlled area had no contact with radioactive materials and are classified in advance as materials releasable into environment.

In order to obtain as much materials releasable into environment as possible, all the efforts are taken to decontaminate, sort as well melt contaminated materials. Part of these waste after treatment and recycling can be released into environment for unconditional use as secondary raw materials (metals, ingots after melting and various building materials – concrete, waste on ceramic and mortar basis). Another part of the waste – scrap from demolition works or recycling activities can be used mainly for backfilling of underground volume after demolition of buildings. The rest of releasable materials not suitable for recycling and for unconditional usage are transported to dump (e.g.: floor coverings, thermal insulation, waterproof isolations, glass…) or specialised dump for hazardous materials (in case of e.g. asbestos materials).

Technological procedures used for non-radioactive waste material treatment in FA Facility decommissioning calculations:

1. Recycling of metals – collection of metals, sorting into containers and transport to the scrap yard (recycling facility).
2. Recycling of building materials - collection of materials, sorting and either using them for backfilling of underground volume after demolition of buildings or reuse of the building materials.
3. Treatment of non-recyclable materials - collection of materials and their transport to the conventional waste dump or specialised waste dumps for hazardous materials.

4.4. Demolition, Site Restoration and Release of Site

4.4.1. Demolition

Demolition of building structures includes preparation of equipment for demolition, breaking of building structures, sorting of materials, loading of debris and transport of debris within the site. These activities are included in parameters of demolition procedures.

Calculation procedures of demolition are assigned to appropriate categories of building equipment. Building equipment includes types of building materials which are supposed to occur within demolition of FA Facility – see Table 3- 3 in Chapter 3.1.4.

Particular building equipment category can be combined with one or more demolition procedures, according to availability of demolition technique for category.

Combinations of building categories used within FA Facility calculations and demolition procedures are shown in the Table 0-4. Chosen default procedures for individual category are marked by full bullet.

Table 0-4 Table of combination of used building equipment categories and available demolition procedures

Building categories	Demolition by excavator	Demolition with explosive	Demolition by hand tools	Demolition by demolition shears	Demolition by wiring saw and excavator	Demolition by oxygen-acetylene cutting set and crane	Demolition by hand tools and crane
Masonry	●	○		○			
Concrete		○		●			
Reinforced-concrete (to 400 mm)		○		●	○		
Steel skeletons						●	○
Rroof skeletons						●	○
Other building materials	●		○				

Note:

default combination ● possible combination ○

Short description of selected demolition is presented in the text below.

Demolition by excavator

This demolition procedure is used for demolition of the following building equipment categories:

- masonry (walls from bricks or blocks with mortar),
- other building material (wood, plastics, glass, ceramics).

Demolition is carried out by mechanism (excavator equipped with shovel). Demolished material is loaded on lorry. Preparatory (transport of equipment to workplace) and finishing activities (terrain arrangements, transport of debris to local stock pile) are included in manpower unit factor (see Annexes 2). Activity ends with rough arranged terrain.

Demolition by demolition shears

This demolition procedure is used for demolition of concrete or reinforced concrete up to thickness of 400 mm. Demolition is carried out by mechanism equipped with hydraulic shears. Demolished material is loaded on lorry. Preparatory (transport of equipment to workplace) and finishing activities (terrain arrangements, transport of debris to local stock pile) are included in manpower unit factor (see Annexes 2). Activity ends with rough arranged terrain. Demolition of each building equipment category has assigned its own manpower unit factor.

Demolition of steel skeletons and roof skeletons by oxygen-acetylene cutting set and crane

Demolition procedure represents demolition of steel building constructions of various shapes and dimensions and demolition of steel roof constructions. Oxygen-acetylene set, electric grinder and mobile crane are used as demolition equipment. Demolished material is loaded on lorry. Preparatory (transport of equipment to workplace) and finishing activities (terrain arrangements, transport of steel scraps to local stock pile) are included in manpower unit factor (see Annexes 2). Demolition of each building equipment category has assigned its own manpower unit factor.

4.4.2. Site restoration

Backfill of underground rooms

After demolition of above FA Facility ground floors and ground floor to the level -1m all underground rooms will be backfilled by debris. The aim is to fill all underground free spaces so that slumping could not happen. Within the OMEGA software backfilling is divided into activities as follows:

- preparation of rooms for backfilling,
- transport of backfill material,
- backfilling of rooms by debris.

Preparation of rooms for backfilling consists of holes drilling through room ceiling. Jack hammers, drilling machines and other demolition tools will be used for the purpose of demolition.

Transportation of building waste procedure consists of lorry loading by jib-type loader or excavator, carriage and unloading of the waste at destined place. Backfilling of rooms by debris comprises preparation and installation of backfilling equipment, implementation of backfilling and compaction of debris using building machinery. Unit parameters are given in the Annexes 2.

Final arrangement of landscape

After backfilling of underground rooms it is necessary to cover up the area by soil layer of 0.8 m and plough layer of 0.2 m thickness. Within the OMEGA software this procedure is considered to be time dependent. Labour content and costs are calculated on the basis of input parameters considering the area and volume of the soil. It is assumed to use lorries and building machinery (dozer, excavator, jib-type loader).

4.5. Management Support and Maintenance Activities

In order to prepare the decommissioning project, a set of preparatory activities are needed and for management of the decommissioning project and for supporting of the main decommissioning activities, as described in Chapter 4.2 to 4.4, as well as during the whole decommissioning project a set of management, supporting and maintenance activities are needed. The standardised list of cost items defines the full list of decommissioning activities for which the costs are to be calculated. The basic description of individual decommissioning activities is presented in the document [7]. For the given decommissioning project, the activities of this type are defined as selection from this full list of activities.

For the case of the FA Facility, following period dependent activities were preliminary selected for the preparation of the decommissioning project, for management and maintenance and for supporting of the inventory dependent activities presented in Chapters 4.2 to 4.4.

01.0103	Preparation of final decommissioning plan.
01.0104	Safety and environmental studies.
01.0201	License applications and license approvals.
01.0202	Public consultation and public inquiry.
01.0301	Radiological surveys for planning and licensing.
01.0401	Hazardous material surveys and analyses.
01.0501	Prime contracting selection.
02.0301	Drainage and drying or blowdown of all systems not in operation.
02.0401	Sampling for radiological inventory characterisation in the installations after plant shutdown, defueling and drainage and drying or blowdown of systems.
02.0402	Subgrade soil sampling and monitoring wells to map contamination plumes.
02.0501	Removal of system fluids (water, oils, etc.).
03.0101	General site-dismantling equipment.
03.0201	Equipment for personnel and tooling decontamination.
03.0301	General radiation protection equipment.
03.0401	Equipment for the surveillance and maintenance.
04.0601	Reconfiguration and maintenance of essential services and facilities to support long-term storage and/or decommissioning operations.
04.2001	Final site survey.
04.2101	Characterization of radioactive materials for recycling and reuse.
04.2101	Characterization of radioactive materials for final disposal.
04.2101	Characterization of radioactive materials for final disposal.
04.2301	Personnel training, training of new personnel.
05.0101	Analyses for handling, packing, storing of waste.
05.0201	Analyses for waste transports.
05.0301	Special permits, packing and transport requirements.
06.0101	Site security operation and surveillance.
06.0201	Inspection and maintenance of buildings and systems in operation.
06.0301	Site keeping.
06.0401	Energy and water - operation and maintenance and consumables.
07.0201	Final cleanup and landscaping.
07.0301	Independent compliance verification with cleanup.
08.0100	Mobilisation and preparatory work.

08.0201	Project manager and staff.
08.0301	Public relations.
08.0403	Decommissioning support including chemistry, decontamination.
08.0501	Health physics.
08.0601	Removal of temporary facilities.
11.0000	Other costs.

Parameters for these period dependent activities (duration, work group composition, manpower) together with their investments and expenses are presented in Annex 2-3.

The set of managing and supporting activities is tentative in order to document the method of managing of these activities in the calculation case. More accurate adjustment of these types of activities requires study of site specific features, like site management, site services, support activities, etc. applicable for the project decommissioning.

5. Waste Management Scenarios for FA Facility

5.1. Waste Management Scenarios – General Approach

Initial state for characterisation of waste arisen from decommissioning process in FA Facility is the state when all spent nuclear fuel in basins has already been transported to another spent fuel storage facility and all liquid and solid operational waste is treated. That means neither stored spent fuel nor water in storage basins is an object of decommissioning process and therefore these wastes are not considered in our decommissioning calculations.

Regarding waste production, decommissioning of nuclear facility such as FA Facility consists of the following activities:

- Activities on radioactive equipment before their dismantling such as pre-dismantling decontamination, partial dismantling, storage and transport of materials. These activities produce liquid and solid radioactive waste (RAW) from pre-dismantling decontamination, waste from partial dismantling and construction works majority of which is non-contaminated waste.
- Dismantling of technological equipment in controlled area produces substantial part of decommissioning waste. All produced waste is treated as RAW, non-contaminated waste arise after sorting procedures.
- Decontamination of building surfaces generates mainly RAW (contaminated building parts or other secondary RAW such as decontamination foams or gels).
- Dismantling of non-active technological equipment out of controlled area. All waste is classified as non-radioactive as it did not come into contact with radioactivity.
- Demolition of building after final radiological measurement guarantying that all radioactivity inside is below the limits for release into environment. Therefore all waste is classified as non-radioactive.
- Final fieldworks of the area, e.g. backfilling of underground floors with releasable building material from demolition works, which does not produce additional waste.

Decommissioning process generates radioactive waste which is necessary to treat, condition and transport either to repository or into the environment if it meets all the limits and conditions for release of the materials. Following chapters describe waste scenarios for solid and liquid RAW. These scenarios represent general schemes of RAW management applied in Slovakia and fully cover produced decommissioning wastes from FA Facility.

The system for management of material and radioactivity flow, as developed in the computer code OMEGA, implements the nuclide resolved limits for material release from decommissioning activities and also the nuclide resolved limits for final disposal at the LLW/ILW Mochovce repository (the Slovak Republic), according the actual legislative in Slovak Republic. The values of these limits are presented in the Annex 3.

5.2. Waste Scenarios for Solid Radwaste

Solid RAW are represented mainly by primary waste from decommissioning such as materials from dismantled technological equipment (pipes, valves, pumps, motors, thermal isolation, cables etc.) as well as building equipment (concrete, masonry, steel skeletons etc.). In addition, solid RAW as secondary waste are produced during the whole decommissioning process (protective clothing, respirators, various textiles, filters, used dismantling tools etc.). Solid RAW can be in general divided into the following categories:

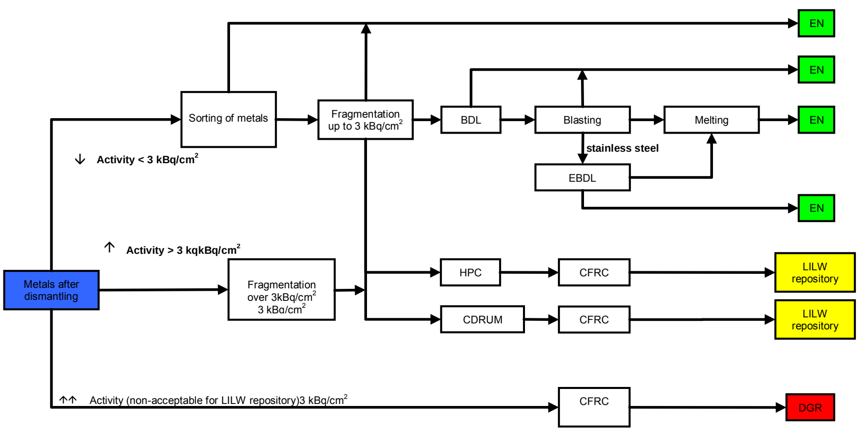
1. metal RAW:
- carbon steel,
- stainless steel,
- colour metals (copper, aluminium).

2. non-metal RAW:
- combustible: textiles,
- compactable: cable isolations, plastics, small building debris,
- non-compactable: suitable only for cementation to drums and subsequently to FRC containers.

5.2.1. Waste scenario for metal RAW

Waste management scenario for metal RAW arisen from decommissioning applied in tentative calculations for FA Facility has three basic endpoints classified according to radioactivity of dismantled metals. Individual waste routes are displayed in Figure 5- 1.

Figure 0-5 Waste management scenario for metal RAW



where:

BDL	- wet bath post-dismantling decontamination
Blasting	- dry post-dismantling decontamination by metal abrasives
EBDL	- electrochemical bath post-dismantling decontamination of stainless steels
HPC	- high-pressure compaction
CFRC	- cementation into FRC containers
CDRUM	- cementation of metal RAW into drums
ENV	- environment
LILW	- near surface LILW repository in Mochovce
DGR	- deep geological repository

Based on radioactivity level it is possible to divide dismantled metal RAW from Figure 0-5 into following groups:

1. <u>Dismantled metal RAW with surface contamination below 3kBq/cm^2</u> are later fragmented and decontaminated if necessary. Depending on the level

of contamination fragmented and decontaminated metal RAW can be either released into environment or are destined to melting process and subsequently released into environment. In case of higher contamination of segmented metal RAW (when meeting limits for the release of materials neither by decontamination nor melting is possible) such materials are compacted or cemented into drums, placed into FRC containers and disposed of in the near surface repository in Mochovce.

2. Dismantled metal RAW with surface contamination above 3kBq/cm^2 are fragmented on special remote controlled fragmentation facility. These fragments are either treated by high-pressure compaction or in case of higher radioactivity above technological limits for the compactor are such metals cemented into drums subsequently into FRC containers and disposed of in the near surface repository in Mochovce.
3. In case of very high contamination or activation of metal RAW acceptance limits for the near surface repository in Mochovce cannot be met. Such dismantled metal RAW are directly conditioned (e.g. by cementation) into containers for deep geological disposal facility. For these metal RAW remote controlled fragmentation is reduced to achieve necessary dimensions for containers destined to DGR.

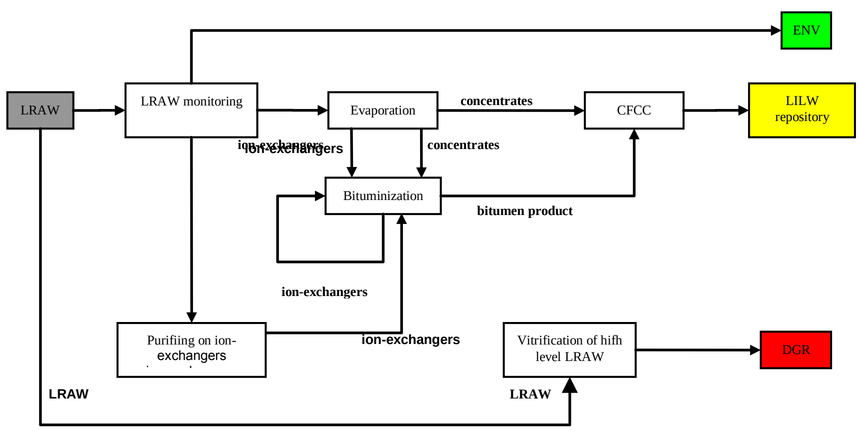
5.2.2. Waste scenario for non-metal solid RAW

Non-metal solid RAW after dismantling are sorted into 5 groups of materials:

- materials releasable into environment directly without treatment,
- combustible RAW,
- low-pressure compactable RAW,
- high-pressure compactable RAW,
- other non-metal solid RAW.

The above listed groups of non-metal solid RAW are clearly displayed in Figure 5- 2.

Figure 5- 2 Waste management scenario for non-metal solid RAW



where: LPC - low-pressure compaction.

Figure 2- 2 shows that in case of non-metals beyond the limits for free release into environment the final waste packages are disposed of in the near surface repository. Ash as the product of incineration of combustible non-metals

RAW is mixed with paraffin, compressed in high-pressure compactor and finally cemented into FRC containers. Water as secondary waste from incinerator are used for preparing of active cement grout for filling FRC containers.

Other non-metal solid RAW are non-compactable and non-combustible RAW, such as contaminated concrete, scrap from grinding of contaminated building surfaces, are cemented into drums, placed into FRC containers and destined to the near surface repository.

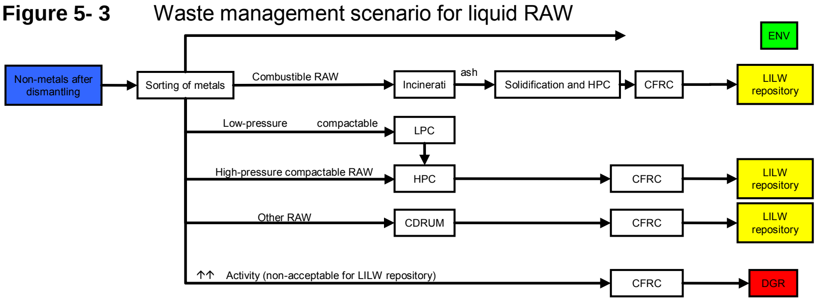
5.3. Waste Scenario for Liquid Radwaste

Liquid RAW from decommissioning are exclusively generated as secondary waste. Namely various used decontamination solutions from pre- and post-dismantling decontaminations of technological equipment and from decontamination of building surfaces. Moreover condensates and water from incinerator and from other RAW treatment technologies as well as water from sanitary loops.

Liquid RAW (LRAW) after radioactivity monitoring can be divided to four waste groups (see Figure 5- 3):

1. LRAW releasable into environment.
2. LRAW advanced to evaporation procedure.
3. LRAW advanced to cleaning on ion-exchanger filters before any other treatment procedure.
4. LRAW with high activity advanced to vitrification procedure.

Figure 5- 3 Waste management scenario for liquid RAW



LRAW from the first group are discharged into environment directly after monitoring or after cleaning on ion exchanger filters.

Second group of LRAW are concentrated in evaporation unit later on either treated in bituminization plant or are used as an active cement grout for cementation of filled FRC containers destined to the near surface repository. Condensates from bituminization plant are cleaned on ion-exchangers, monitored and discharged into environment.

In order to reduce the radioactivity level of the third group of LRAW, which does not meet radioactivity limits for evaporation unit, this LRAW is cleaned on ion-exchangers, subsequently concentrated in evaporator and later on treated as the second group of LRAW .
Clean-out of liquid media during operation, decommissioning or treatment on evaporation unit and bituminization plant respectively generates spent ion resins as the secondary RAW which are usually bituminised in drums and cemented in disposal containers disposed of in the near surface repository. Just in case of very high radioactivity of spent ion resins these are solidified in vitrification matrix. Vitrified cartridges are stored in special storage and are destined to deep geological repository. However, this type of waste is produced only in case of non-standard operation of nuclear facility. Given route is displayed on Figure 5-3 only to demonstrate an ability of treatment such waste within waste scenario for liquid radwaste. For our OMEGA code calculations we do not suppose generation of given type of waste during FA Facility decommissioning.

Calculated quantities of liquid radwaste, such as contaminated waters, concentrates from evaporation unit and spent ion resins from FA Facility decommissioning are presented in Chapter 7.

5.4. General Scheme for Waste Management

Based on data of individual waste treatment and conditioning technologies, related to real flow of radioactive materials within the system for management of waste from decommissioning and from operation of the NPP's in Slovak Republic, the complete waste flow was implemented in the computer code OMEGA.

6. Calculation Structure

The chapter reviews the basic characteristics of the standardised cost structure for decommissioning purposes and the methods for its implementation into the real decommissioning projects.

6.1. Standardized Cost Structure – Review

The standardised structure for decommissioning purposes was issued by OECD/NEA, IAEA and EU in 1999 in the document “A Proposed Standardised List of Costs Items for Decommissioning Purposes” (PSL) [7]. The document defines the structure of decommissioning activities for which the costs are to be presented. 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 worldwide interests to all decommissioners.

Basic chapters of standardised cost items:

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.

The standardised structure defines following cost groups:

12.0100 Labour costs.
12.0200 Capital, equipment and material costs.
12.0300 Expenses.
12.0400 Contingency.

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 in principle represents the system of decommissioning activities structured in above listed numbered chapters. The main aim was to develop a structure for presenting the costs for decommissioning, but at the same time it can be used also for presenting other decommissioning parameters of 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.

On the present, a new revised cost structure for decommissioning purposes is being developed by OECD-NEA, European Commission and IAEA, to be known as the International Structure for Decommissioning Costing (ISDC). This revised structure will come out from PSL structure and will ensure greater overall coherence at the different hierarchical levels of the cost structure and the avoidance of ambiguities in the definitions of specific cost items comparing to PSL. Issue of the new ISDC structure is expected in near future.

6.2. Methods of Implementation of Standardized Cost 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 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. This structure is repeated in various sections of the whole 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 PSL 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 reflects also these requirements, it means that it should contain also the data needed for the generation of the standardised calculation structure.

The standardised calculation structure has also some special features which reflects the fact that the similar or the same decommissioning activities (again for example the 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.

6.3. Implementation of Standardized Cost Structure in Omega Code

The implementation of the standardised structure of decommissioning activities, in order to achieve the standardised costs structure, can then be characterized in three main steps:

- Development of the detailed standardised structure of activities with numbered levels.
- Development of the decommissioning database with data elements enabling the generation of the standardized calculation structure.
- Generation of the standardized calculation structure.

- Management of the standardized calculation structure.

The first step represents developing detailed standardised structure of decommissioning activities by extending three numbered levels of the published standardised structure. The extending represents 3 to 5 additional numbered levels, depending on the section of the standardised structure. In this way, a set of templates of standardised structure can be developed which are then used for generating of the standardised calculation structure in interaction with the decommissioning inventory database.

The second step is characterized by implementing additional database items related to premises items and decommissioning inventory items (Chap. 4.4):

- 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.

For generation of the standardized calculation structure in the third step it is needed to develop also additional data which enable to generate the room oriented calculation structure according to the definition of individual sections of the standardized structure.

The simplified procedure for the implementation of the standardised structure of decommissioning activities is following (an example of the generated standardised cost calculation structure is presented on the Figure 0-6):

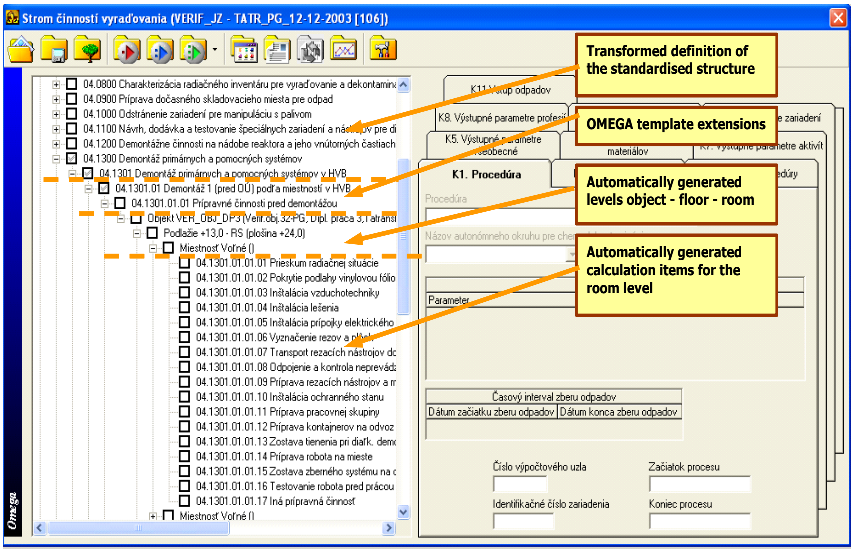
1. Utilization use the standardised PSL structure as the input data
   - the original structure is categorized up to the third numbered level,
   - list of decommissioning activities is defined for the lowest levels.
2. Developing of the standardised template structures
   - extended standardised structure with lower numbered levels.
3. Developing of the standardised structure of the calculation option (static structure)
   - user defined specific structure based on a selected template structure at lowest levels, where applicable, modes for generating of lower calculation levels are defined, e.g. object / floor /room / equipment structure.
4. Generation of the executive standardised calculation structure

– generated based on static standardised structure and facility inventory data,
– extent of calculation is defined by the user by switching decommissioning activities in generated executive calculation structure.

Example of the executive calculation is on the Figure 0-6. The duration of generation of the calculation structure at the current level of the code is approximately 20–25 hours for the calculation structure for a typical NPP and the number of calculation items is between 10^4 to 10^5. The calculation process itself for such a calculation extent lasts approximately 30 hours including generation of output formats and the Gantt chart. For the case of the model FA Facility calculation this values are of two orders lower.

This three–stage style of the work enables flexibility in developing the standardised calculation structures for any nuclear facility. The precondition is the inventory database for the nuclear facility with relevant structure and data needed for application of standardised structure. The methods for development of the inventory database with these properties were developed and applied for developing the calculation structure for model calculations for FA Facility.

Figure 0-6 Example of an executive standardised cost calculation structure

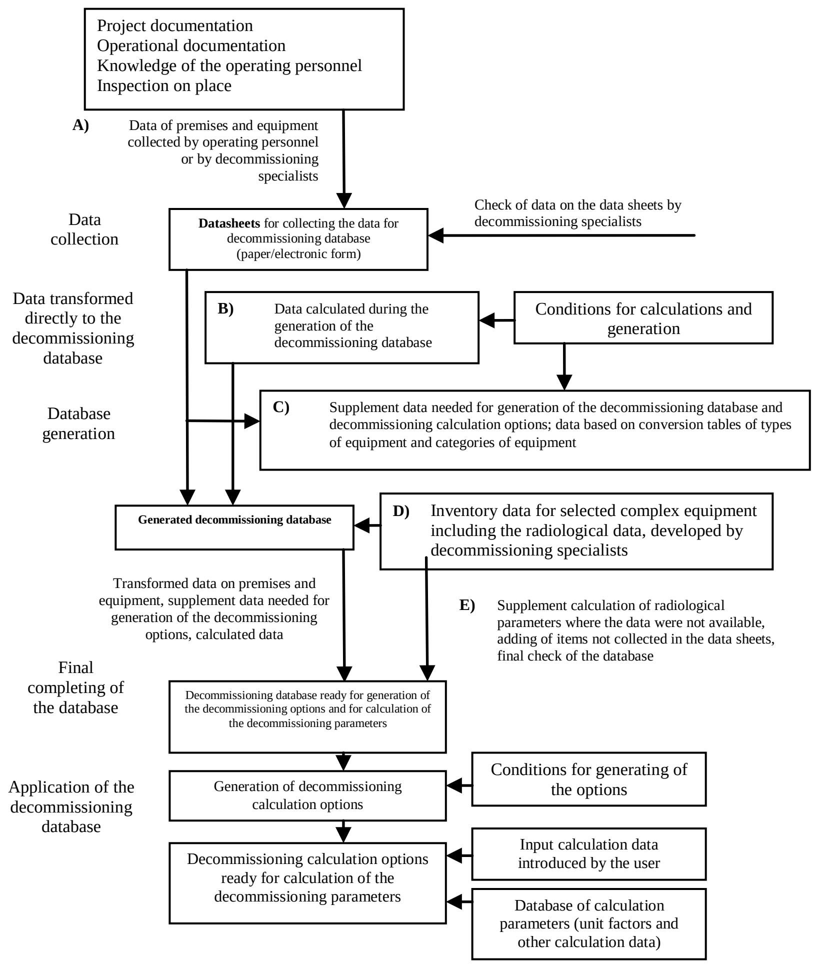


6.4. Executive Calculation Structure of FA Facility

The executive calculation structure for the FA Facility was developed based on the procedure described in Chapter 6.3. The structure contains all decommissioning activities as described in Chapter 4. The calculation structure was generated based on the developed inventory database of the FA Facility and a standardised template developed from the general template of the standardised decommissioning structure developed for OMEGA code.
Before the generation of the standardised calculation structure for the FA Facility, the developed inventory database is completed for data needed for generation of the calculation structure, as described in the Chapter 6.3.

The complete procedure from developing the inventory database to generating of the executive calculation structure is presented on the Figure 0-7.

Figure 0-7 Principal phases of development of the inventory database and generating of the calculation structure



Data of “A” type are the primary data to be collected from facility technical documentation and based on physical inspection in individual premises of the facility.

Data of “B” type are the secondary data derived from the primary data by calculation by decommissioning experts.

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.

Data of “D” type are the complete inventory data for complex 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 correspond to proposed dismantling procedure. Similar aproach 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. This is not the general case for the FA Facility. The only equipment, for which this procedure could be applied in the frame of upgrading of the inventory database, is the refuelling machine.

Data of “E” type are in general the radiological data, mostly the contamination levels and the nuclide composition of contamination or dose rate. It is expected that the main radiological parameters (the dose rate in the defined distance (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. Assessed Changes

Re-calculation of FA Facility decommissioning parameters (2011) as well as former tentative calculations [1] (2007) are made in the OMEGA code.

Concerning OMEGA code no changes in mathematical models of procedures, functions and systematic of material and radioactivity flow has been made since former tentative calculations. Whole mathematical apparatus implemented within the OMEGA code algorithms remained intact except of personnel exposure calculation where new optimised approach was implemented. Optimisation of exposure calculation consists of managed sequence of dismantling equipment within the room where equipment is being dismantled in order from the highest dose rate equipment to lower ones. This optimisation lowers average dose rates in room during dismantling and consequently saves personnel exposure.

Input FA facility inventory database remained the same. Amount of database items, their weight, surface area, material composition, contamination levels of active components including distribution among four contamination classes, nuclide vector and also dates of nuclide vector for contaminations and dose rates are without any change.

Changes were made in input calculation databases mainly in database tables of workers' salaries, cost unit factors of consumables, materials and substances, manpower unit factors for individual decommissioning activities.

Changes of labour cost unit factors

Input values of individual profession labour cost unit factors (salaries hour rates) have changed comparing to previous tentative calculations. Labour cost unit factors data used in former tentative calculations were obtained for Slovak conditions because no relevant Swedish data were available in that time. New re-calculations use Swedish up-to-date salaries hour rates estimated by Swedish labour market rates. Changes are shown in following table. It can be seen that salaries have approx. 5 to 10 times higher values in up-to-date Swedish salary levels for 2011 to previously used Slovak data.

Table 0-5 Comparison of labour cost unit factors between tentative calculations and new re-calculations

Profession	Labour cost unit factor [€/manhour]	
	Tentative calculations 2007	Re-calculation 2011
manager (average personnel on the management level)	14	135
senior engineer (experienced engineer, more than 10 years of experience in the field)	8	38,6
engineer (standard engineer)	6,5	30,8
operator (qualified operator in relevant branch)	5	30,8
administrative worker	5	26,7
worker (skilled, qualified craftsman)	4	21,6
auxiliary worker (only basic training)	2	21,6

Labour cost unit factors are also listed in Annex 2-1.

Changes of cost unit factors for all procedures

All procedures use the same database of cost unit factor parameters for calculations. Within these parameters changes were made as follows:

- Prices of cost unit factors of consumables, materials and substances were increased in general for all techniques. Some of cost unit factors were increased multiplicatively. Reasons are in using of old Slovak data and also using of old types of some consumables, materials and substances in former calculations which were changed to new values based on up-to-date average international market prices.
- Investment costs (depreciations) and also expenses were increased according to inflation rates from 2007.

For more detailed information on main cost unit factors values see Annex 2-1.

Changes of parameters for dismantling procedures

For dismantling technologies changes were made as follows:

- Extensive adjustment of manpower unit factors for individual combinations of dismantling techniques with categories of equipment. Adjustment came out from price catalogue CENKROS [16] developed for evaluation of building activities in Slovak Republic and were adapted for decommissioning purposes. In general, dismantling manpower unit factors per mass unit were decreased within this adjustment.
- Consumption unit factors for individual combinations of dismantling techniques with categories of equipment were adjusted also based on data from CENKROS.
- Changes of working groups for individual technologies – amounts of workers for individual professions were adjusted.
- For remote dismantling techniques some manpower unit factors (capacities) were adjusted based on new available technical data and experiences.
- Manpower unit factors for preparatory and finishing activities for dismantling were adjusted. In general, manpower unit factors were decreased within this adjustment based on practice feedback.

For more detailed information on these procedures and parameters values see Annexes 2-2-1, 2-4 and 2-5.

Changes of parameters for building surfaces decontamination procedures

For decontamination technologies

- Consumption unit factors for individual combinations of dismantling techniques with categories of equipment were adjusted also based on data from CENKROS.
- Changes of working groups for individual technologies – amounts of workers for individual professions were adjusted.

For more detailed information on these procedures and parameters values see Annex 2-2-2.

Changes of parameters for demolition procedures

For demolition technologies changes were made as follows:

- Extensive adjustment of manpower unit factors for individual combinations of demolition techniques with categories of equipment. Adjustment came out from new available catalogues of demolition machinery and tools and also price catalogue CENKROS. In general, demolition machinery capacities increased i.e. manpower unit factors per mass unit were decreased within this adjustment.

- Prices of cost unit factors of consumables, materials and substances were increased in general for all techniques. Some of cost unit factors were increased multiplicatively. Reasons are in using of old Slovak data and using of old types of some consumables, materials and substances in former calculations which were changed to new values based on up-to-date average international market prices.
- Investment costs (depreciations) and also expenses were increased according to inflation rates from 2007.

For more detailed information on these procedures and parameters values see Annex 2-2-3.

Changes of parameters for waste management procedures

Waste management procedures include technologies of waste treatment, conditioning, transport and disposal of final packages or releasing of materials. Within these procedures following changes were made:

- Changes of manpower unit factors of some technologies - for some technologies manpower unit factors were increased and for some they were decreased.
- Changes of working groups for individual technologies – amounts of workers for individual professions were adjusted.
- Prices of cost unit factors of consumables, materials and substances were increased in general for all technologies. Some of cost unit factors were increased multiplicatively. Reasons are in using of old Slovak data and using of old types of some consumables, materials and substances in former calculations which were changed to new values based on up-to-date average international market prices.
- Investment costs (depreciations) and also expenses were increased according to inflation rates from 2007.

For more detailed information on these procedures and parameters values see Annexes 2-2-4, 2-2-5 and 2-2-6.

Changes of parameters for time-dependent procedures

Complete list of time-dependent procedures was revised. Within these procedures following changes were made:

- Some time-dependent procedures were removed and some were added comparing to previous tentative calculations.
- Changes of working groups all time-dependent procedures – amounts of workers for individual professions were adjusted.
- Duration of individual time-dependent procedures during the decommissioning project was revised and adjusted. In general, durations were decreased.
- Investments and expenses costs were revised and adjusted for individual time-dependent procedures

For more detailed information on these procedures and parameters values see Annex 2-3.

8. Results of Calculation

Decommissioning cost re-calculations of FA Facility were performed for scenario with wet bath post-dismantling decontamination equipment for iron/steel radwaste and melting equipment for iron/steel radwaste technologies available at decommissioning site. These radwaste management technologies are used within decommissioning process to enhance amount of steel (mainly carbon steel) releasable from facility decommissioning.

Within the calculation following set of output parameters was calculated:

- Results of main decommissioning parameters, such as costs, manpower and exposure of personnel.
- Results characterizing distribution of materials arisen from decommissioning, such as mass distribution of metals, non-metals destined to repositories or released into environment and also number of disposed radioactive waste containers for NSR.

These parameters were calculated for individual activities within calculation based on the PSL structure. Parameters are presented in following forms:

- Results presented within PSL structure. Main parameters costs, manpower and exposure of personnel for given PSL items are listed in individual tables. Tables are presented in Annex 4- 1, due to large extension PSL items. This type of results allows browsing whole decommissioning project on detailed level.
- Summarized results for whole project. Costs, manpower, exposure and distribution of carbon steel are presented within these results. These results are presented in table and graph form and allow analyzing decommissioning option on overall level and comparing of individual options.
- Work breakdown structure – time schedule. This time schedule allows viewing time distribution of individual decommissioning activities during decommissioning process.

Results from previous tentative calculations [1] for the same radwaste scenario (S1 in original document) are also presented here for comparing the changes of output parameters.

Summarized results and graphs with commentaries both for re-calculated and former tentative calculated parameters are presented in following text. Overall values of costs, manpower and exposure for given decommissioning option are listed in

Table **0-6**. Graphs related to this table are shown on Figure 0-9, Figure 0-10. Summary distribution of materials from decommissioning of FA Facility is presented in Table 8- 2.

Distribution of carbon steel arisen from decommissioning of FA Facility (contaminated, non-contaminated from dismantling of technological equipment and non-contaminated from demolition of building structures) is listed in Table 0-8 with associated graph on Figure 0-11. Detailed values of manpower, exposure and costs for individual activities within decommissioning process for re-calculated scenario are shown in PSL structure in Annexes 4.

Table 0-6 Values of main overall output decommissioning parameters - manpower, exposure, costs

Overall parameter	Unit	Re-calculation 2011	Tentative calculation 2007 Scenario S1
Manpower	[manhours]	126 196	233 660
Exposure	[manmicroSv]	24 591	74 548
Costs	[€]	7 956 185	4 313 871

Table 0-7 Summary distribution of materials from decommissioning

Output materials	Unit	Re-calculation 2011	Tentative calculation 2007 Scenario S1
Metal materials released to environment	kg	349 475	349 461
Non-metal materials released to environment	kg	1 838 693	1 838 693
Metal RAW to repositories	kg	3 903	3 917
Non-metal RAW to repositories	kg	5 191	5 191
Amount of disposal containers FRC to repositories	pc	13,91	13,96

Table 0-8 Distribution of carbon steel from decommissioning

Carbon steel endpoint	Re-calculation 2011		Tentative calculation 2007 Scenario S1	
	Mass [kg]	Ratio [%]	Mass [kg]	Ratio [%]
Carbon steel released in the environment after dismantling	52 916	15,14	52 916	15,14
Carbon steel released in the environment after post-dismantling decontamination	96	0,03	11	0,00
Carbon steel released in the environment after post-dismantling decontamination and melting	25 228	7,22	25 299	7,24
Building carbon steel released in the environment	268 171	76,71	268 171	76,71
Carbon steel disposed in LILW repository	3 172	0,91	3 186	0,91
Carbon steel disposed in DGR	0	0,00	0	0,00
Total mass of carbon steel	**349 583**	**100,00**	**349 583**	**100,00**

Figure 0-8 Decommissioning costs

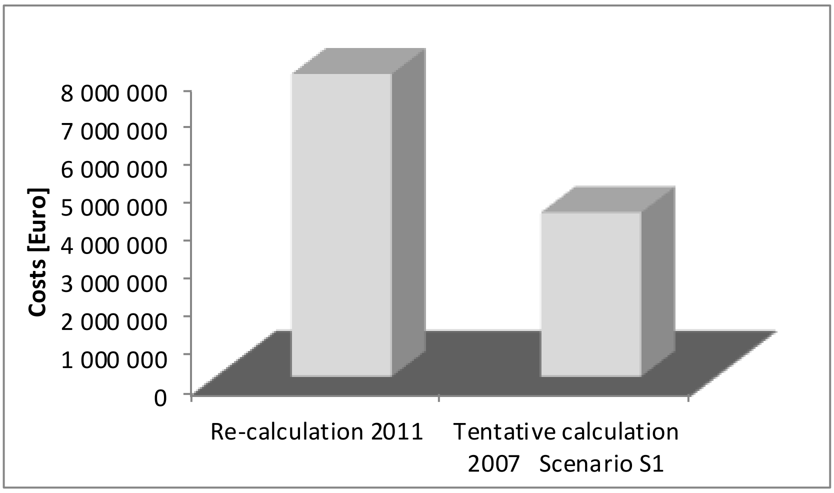


Figure 0-9 Decommissioning manpower

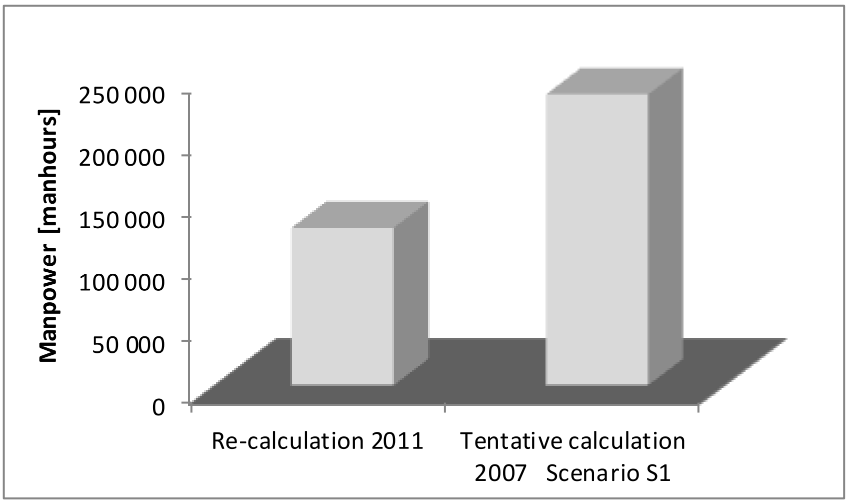


Figure 0-10 Decommissioning personnel exposure

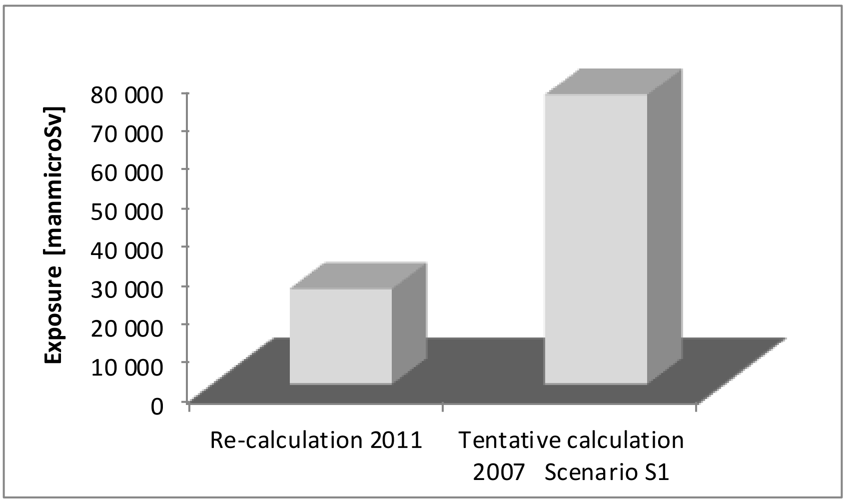
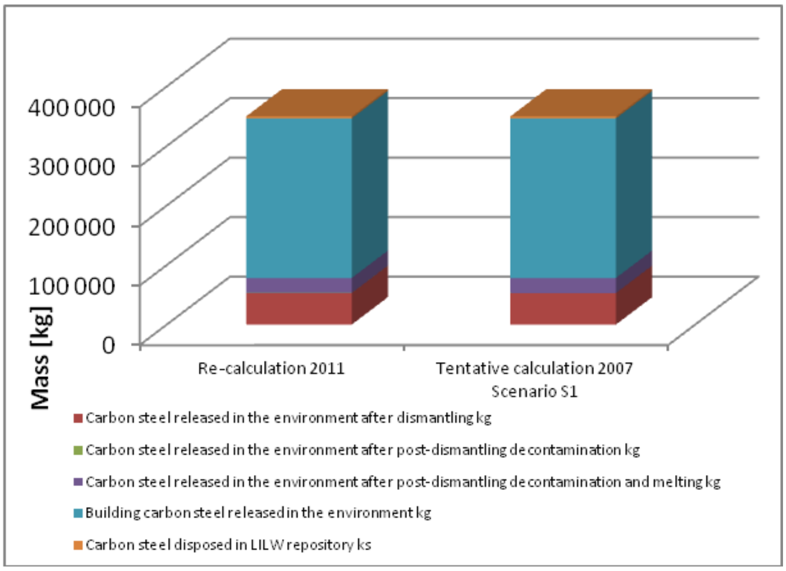


Figure 0-11 Distribution of carbon steel from decommissioning



Based on comparison of new re-calculated and former tentative calculated values of overall output parameters (see

Table 0-6 and Figure 0-9, Figure 0-10, Figure 0-11) and on Annexes 4-3 and 4-4, following observations and rationales are presented:

Manpower

Manpower has decreased from 233 660 to 126 196 manhours. This decrease is caused by following reasons:

- Decrease of duration of individual time-dependent activities – time for individual time-dependent activities (e.g. documentation preparation, licensing, etc.) has been reviewed and decreased based on experience from previous decommissioning project planning.
- Changes of working groups for individual time-dependent and also inventory-dependent activities – working groups were optimised and adjusted based on the above mentioned experience. In general, amount of workers has decreased.
- Changes of manpower unit factors - manpower unit factors has been reviewed and adjusted based on new information sources (see Chapter 7).
- Decrease of manpower from PSL Chapter 11 Other costs – based on gained experience in decommissioning costing all workforce should be identified and assigned in appropriate activities of PSL Chapters 1 – 10 and Chapter 11 should not contain any workforce.

Exposure

Personnel exposure has decreased from 74 548 to 24 591 manmicroSv. This decrease is caused by following reasons:

- Decrease of manpower for whole decommissioning project – according to changes in manpower unit factors, amount of workers within individual working groups manpower of activities and adjustments in time-depending activities manpower has decreased (see Manpower above).
- Radioactive decay of nuclides in nuclide vector – dominant nuclide responsible for dose rates is Co-60, time difference between tentative calculations and re-calculation is four years i.e. nearly one half-life of Co-60.
- Optimisation of exposure calculation – according to organised dismantling calculation approach where equipment is being dismantled in order from the highest dose rate equipment to lower ones optimisation lowers average dose rates in room during dismantling and consequently saves personnel exposure.
- Review of personnel exposure for time dependent procedures for relevant activities according to individual main PSL chapters.

Costs

Costs has increased from 4 313 871 to 7 956 185 €. This increase is caused by following reasons:

- Higher labour cost unit factors (salaries hour rates) is the main driver for increase of calculated costs despite the fact that the total manpower is significantly lower than in former tentative calculation. New re-calculations use Swedish up-to-date salaries hour rates delivered by SSM which are approx. 5 to 10 times higher (see Table 7-1).
- Increase of investments and expenses for time dependent activities due to new obtained knowledge in this field and increase of investment costs (depreciations) and also expenses for inventory depended activities according to inflation rates from 2007.

- Prizes for consumables, substances and materials (electricity, water, waste packages, etc.) are generally higher and were changed to in accordance with up-to-date average international market prices.

Summary distribution of materials from decommissioning and distribution of carbon steel

Summary distribution of materials from decommissioning and distribution of carbon steel remain almost the same for both calculations. This is due to following reasons:

- Input inventory database of FA Facility - remain the same for both calculations including physical and radiological characteristics.
- Negligible effect of radioactivity decay – distribution of radioactive materials from decommissioning is affected also by Cs-137 and alpha nuclides, despite the fact they represent only very small part of contamination (see contamination vector composition in Chapter 3.1.4). These nuclides have half-time of decay of tenths and hundreds of years and time difference of individual decommissioning calculations is approximately 4 years, it means that effect of Cs-137 and alpha nuclides time decay is not so rapid comparing to Co-60 (the main contaminant). From this reason, changes in distribution of materials from decommissioning according to radioactivity are negligible.
- Step function of material distribution dependent on release and disposal radioactivity limits – according to their radioactivity, materials are distributed among three final groups – release to environment, near surface repository, deep geological repository. This distribution has step function characteristics – materials are switched from one group to another just after reaching stipulated radioactivity interval endpoints for individual nuclides. It means that distribution of materials among final groups does not copy continual decrease of material radioactivity in time.

Tentative decommissioning schedule for decommissioning re-calculated option is shown in Annex 5. From this tentative schedule it can be seen that entire decommissioning project has duration of approximately 3,5 calendar years. Duration of relevant groups of activities and individual activities can be identified in the schedule according to the PSL structuring.

9. Conclusion

New valuated FA Facility decommissioning parameters including costs, manpower, exposure, output materials distribution and tentative schedule of decommissioning are presented in this report. Valuation of parameters was carried out by using OMEGA code, decommissioning costs and other parameters calculation software developed at DECOM, a. s.

Output parameters were compared with the previous tentative calculations of FA Facility which had been carried out within the former project [1] to show development of calculated parameters in dependence on input parameters change. The main reason for valuation was using up-to-date Swedish labour costs data and also use of international market consumables, substances and material unit costs comparing to previous calculation where Slovak origin data were used. Changes in other calculation parameters and progress of OMEGA software since first tentative calculations of FA Facility decommissioning in 2007 were other reasons.

Valuation uses the same FA Facility inventory database and presents output parameters in the same way as former tentative calculation by using standardized decommissioning cost calculation structure PSL [7] recommended for application in decommissioning costing by the main European organizations involved in decommissioning (IAEA, EC and OECD/NEA).

From the valuation outcomes and their comparing with former tentative calculation values it can be stated that according above mentioned changes of input conditions and parameters the costs of FA facility is almost doubled despite that manpower is half of former values. Increase of costs is caused by higher Swedish labour cost unit factors which are significantly higher than formerly used Slovak labour costs unit factors. Decrease of manpower is caused by revision of time-dependent activities duration, composition of working groups and manpower unit factors.

New updated calculation can be further optimised. To gain more precise estimates of decommissioning parameters the accuracy of input parameters should be enhanced by upgrading of the FA Facility inventory database (technological and mainly radiological characterization) by model calculations for radiological characterisation, by analysis of further possibly available documentation, inspection on site, supplement radiological characterisation including sampling and analyses of samples and also by implementation of Swedish waste management infrastructure into OMEGA database and calculation procedures including final disposal at Swedish repositories with up-to-date costs of disposal per m^3.

The report results show that once a decommissioning project was calculated by OMEGA software it can be adjusted and optimised further with regard to changed input conditions and comparison with previous results is easily possible.

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11. Annexes

Annex 1 **Inventory database of the FA Facility**

- Annex 1- 1 List of the floors
- Annex 1- 2 List of the rooms
- Annex 1- 3 List of the technological and building equipment

Annex 2 **Calculation parameters (most important selected parameters)**

- Annex 2- 1 General parameters
- Annex 2- 2 Parameters of technological procedures
  - Annex 2-2- 1 Set of calculation procedures for dismantling of technological equipment
  - Annex 2-2- 2 Set of calculation procedures for decontamination of building surfaces
  - Annex 2-2- 3 Set of calculation procedures for demolition of building
  - Annex 2-2- 4 Set of calculation procedures for treatment technologies
  - Annex 2-2- 5 Set of calculation procedures for radiation monitoring
  - Annex 2-2- 6 Set of calculation procedures for transports
- Annex 2- 3 Parameters of specific procedures (Period depended activities)
- Annex 2- 4 Extent of preparation and finishing activities for dismantling, 04.1300 - Removal of primary and auxiliary systems
- Annex 2- 5 Extent of preparation and finishing activities for dismantling, 04.1500 - Removal of other material/equipment from containment structure and all other facilities, or removal of entire contaminated structures

Annex 3 **Radiological limits for unconditional release of materials to environment implemented in OMEGA code**

Annex 4 **Calculated output parametres**

- Annex 4- 1 Lists of calculated decommissioning activities and results of calculation, according the PSL structure
- Annex 4- 2 Distribution of costs – re-calculation 2011
- Annex 4- 3 PSL structure of calculated decommissioning activities – Summary Tentative calculation 2007
- Annex 4- 4 PSL structure of calculated decommissioning activities – Summary re-calculation 2011

Annex 5 **Tentative schedule of the FA Facility decommissioning project**

2012:08

The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 270 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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