

**Focus on International Co-operation in D&D Cost Estimations for Research Reactors and the Role of the IAEA in It - 9363**

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**ABSTRACT**

Estimating decommissioning costs and collecting funds are the prerequisites for safe, timely and cost effective decommissioning. These issues were addressed by main international organizations involved in decommissioning – IAEA, OECD/NEA and European Commission. While the activities of OECD/NEA and European Commission are focused mainly on nuclear power plants, the activities of IAEA involve the whole spectrum of nuclear facilities worldwide and the aspects of decommissioning of research reactors, due to their spread in member states, have the special position in IAEA activities. The experience in decommissioning of research reactors was accumulated in developed countries and international activities are needed to support the planning and implementation of decommissioning of research reactors in other IAEA Member States. Decommissioning costing plays the key role among these issues. One of the main results of the common effort of the above listed organisations in costing is the standardised structure of decommissioning cost items which was jointly published as the common platform for harmonisation in decommissioning costing and is recommended for general use. Main subject of the paper is the preliminary presentation of a new IAEA project planned for the period 2009-2011 with the objectives to develop the robust standardised cost estimation methodology, which implements the standardised cost structure. The aim of the proposed methodology is to support the Member States to prepare their own specific cost estimates for research reactors. The planned target is the parametric cost estimating model applicable for various types of research reactors and for various national decommissioning backgrounds. The model is supported by facility inventory database and database of unit factors and data specific for facility to be decommissioned. The paper reviews main types of research reactors; the current practice for decommissioning costing which will be implemented in the project; presents the proposed approach for the robust cost estimation methodology; principles of implementation of the standardised cost calculation methodology and main planned activities of the project.

**INTRODUCTION**

One of the main messages for future activities in decommissioning costing, it that it is increasingly important to ensure that greater cost effectiveness should be achieved in the management of nuclear liabilities, including research reactors [1]. Possible ways to achieve this is to identify effective solutions for individual decommissioning activities and in this way to optimise the cost. The trend is to achieve a better understanding of decommissioning cost estimates and, based on those, to fine tune the funding mechanisms.

Cost estimate process is a kind of modelling of the decommissioning process. Better understanding of the costing process, clear definition and mutual links of individual costing elements that should reflect all relevant aspects of the decommissioning process, could enhance the modelling of the decommissioning process in order to be closer to the real process. In this way the decommissioning costing will be able also to optimise the decommissioning processes in order to define the optimal cost, time structure and to ensure the safety of the process.

The cost estimates are essential to secure an appropriate level of funding for a decommissioning programme. One of the main features of decommissioning cost estimating of research reactor is the fact that individual cost estimates are based on national or owner's experience and generally they are different as for the structure, methodology implemented and formats of estimated data. The costing methods applied range from simple estimation based on estimated manpower for individual task up to dedicated sophisticated software. This general feature can be identified also in decommissioning costing of power reactors.

Estimating decommissioning costs and collecting funds for decommissioning of facilities that have used radioactive material is a prerequisite for safe, timely and cost effective decommissioning [2]. Costing and funding issues were addressed specifically by main international organizations involved in decommissioning – IAEA, OECD/NEA and European Commission. The strong effort was identified in these organisations for harmonisation in decommissioning costing. The most important result is the proposal of the standardised structure of cost items for costing purposes [3]. Experience with this structure shows that this is practically the only way how to overcome differences identified in decommissioning projects [4], [5]. The standardised structure of cost items, as the list of decommissioning activities, could effectively support the harmonisation in decommissioning costing when this list is used as the common platform for presenting the cost for decommissioning projects cost. Using the standardised list directly as the calculation structure can further facilitate harmonisation in decommissioning costing.

The activities of EC and OECD/NEA are oriented mostly to power generating facilities due to fact that huge amount of finances will be needed for decommissioning project in near future and the finances should be adequately reasoned and appropriately planned. The experience in decommissioning in Europe was already accumulated and the decommissioning is now going to be a standard industrial activity.

The activities of IAEA involve the whole spectrum of nuclear facilities. Aspects of decommissioning of non power generating facilities like research reactors due to their world wide spread in member states have a special position on IAEA activities. The experience in decommissioning of research reactors is accumulated in developed countries and international activities are needed to support the planning and implementation of decommissioning of research reactors outside of the developed countries.

Decommissioning costing plays the key role among these issues. The effort of IAEA is to address the subject from the standpoint of the diverse social, economic and cultural environments that constitute IAEA membership in order to develop a broader background for decision making process and for implementation of decommissioning projects [2]. The proposed IAEA project for robust costing methodology for research reactors, as presented in this paper, is in line with these IAEA initiatives.

## **OBJECTIVES OF THE PROJECT**

There is a trend towards using a comprehensive parametric cost estimating models [1] supported by extensive databases. Research reactors are so varied that each cost estimation case is best approached taking into account the site and facility specific factors and the national background in decommissioning. The main objective of the project is to develop the general robust cost estimating methodology for various types of research reactors. The proposed methodology should support the Member States to develop their national, site and facility specific cost estimates for research reactors.

One of the main efforts of the IAEA for decommissioning costing [2] is the promotion of the standardised cost structure [3] and the proposed robust costing methodology should implement this standardised structure. The international best practice accumulated in decommissioning projects should be also implemented. The latest summary of this experience can be found in [2] and the main principles identified in this documents, should be used in the robust costing methodology. It involves the unit factors approach for hands on decommissioning activities, completed by estimation of cost for period dependent activities, collateral cost and adjusted by contingency.

The costing model should be supported by facility inventory database, database of unit factors and other input data specific for facility, site and national decommissioning background. In this way it is possible to develop the parametric cost estimating model which can be effectively used for periodical updating of the cost estimates. As the research reactors for the purpose of this document are considered small and medium facilities with the power output at the level up to some MW.

## TYPES OF RESEARCH REACTORS

Research reactor facilities are used for a variety of purposes, including training, radioisotope production, irradiation of samples and materials, and industrial processing of material. There are many different types of research reactors and the range of power ratings varies from several watts up to hundreds of megawatts. The complexity varies from relatively simple constructions of critical assemblies up to the complexity comparable with the power reactors [6]. Understanding of aspects such as material and radionuclide inventory, decontamination and dismantling techniques, waste management activities and waste volumes, can be facilitated by classification of research reactors. The types of research reactors which are the subject of the IAEA project are following [7]:

- a) **Pool reactors.** Reactor core is submerged in a pool of water, which usually provides cooling, moderation and shielding. The reactor may also be equipped with a specific moderator or reflector (graphite, beryllium). The power varies from 0 W to over 10 MW. The core is either suspended from a bridge or supported from the floor of the pool. Activation of the pool floors and walls is usually low (power dependent) as a result of the shielding effect of the water. The irradiation facilities of these reactors can include channels penetrating the walls of the pool, devices suspended from the top of the reactor pool, or experimental rigs resting on the pool floor.
- b) **Tank reactors** have the core located within a closed tank, which is generally made of aluminium or steel. The tank is usually surrounded by the cylindrical structure of a graphite or water reflector, an iron or lead thermal shield and a concrete biological shield. Many of these reactors are in the power range of tens of MW. The cooling systems are mainly of the closed circuit type. The irradiation facilities of these reactors are channels that penetrate the vertical and horizontal surrounding walls of the biological shield; these channels sometimes also penetrate the walls of the reactor tank. Such facilities are often connected to large and complex experimental equipment and test loops. The auxiliary systems of some tank reactors (e.g. heavy water) may be complicated, because of the need for special treatment and storage facilities for the heavy water, and the need for an inert cover gas. ARGONAUT reactors (10 kW to 100 kW) are water and graphite moderated thermal neutron heterogeneous reactors. The core lattice consists of a cube of graphite containing rows of material testing reactor type fuel elements located in aluminium tanks containing cooling water. An internal graphite moderator has access holes for experimental purposes. The reactor is shielded by concrete and has an integral water tank and graphite thermal column for use in a variety of experiments.
- c) **Homogeneous liquid reactors** are characterized by a homogeneous liquid mix of fuel and moderator (which also serves as a heat transfer medium) connected through a heat exchanger to an external coolant. Because of this, the fuel moves through the core and a piping system during operation; this may create a serious decontamination problem during the decommissioning process. Usually, additional gas purification (with a recombiner) is installed; this may be highly contaminated.
- d) **Fast reactors** are characterized by the lack of a moderator. The fuel is mainly plutonium oxide or uranium oxide. The only fluid passing through the core is the liquid metal coolant, which is generally sodium, sodium-potassium or mercury. These coolants, which have high reaction rates with water, may impose some difficulties for decommissioning. On the other hand, less activation of the structural materials is expected relative to thermal reactors, because of the lower percentage of thermal neutrons in the core.
- e) **Graphite reactors** use the graphite blocks as the moderator. Graphite is also the main material of the components of the core structure. The fuel rods are inserted among or within the graphite blocks, and the coolant, if needed, is generally gas (usually air), but may sometimes be water.

- f) **Other types.** This group includes mainly critical assemblies and homogeneous solid reactors. In most cases, critical assemblies are heterogeneous reactors, usually operated at source multiplication levels, just below or at criticality. Because of this, the radionuclide inventory is low and no significant hazard or technical complication is involved in decommissioning. Homogeneous solid reactors generally have a very low power. The fuel is homogeneously embedded in a solid moderator (e.g. polyethylene). The reactor core may be surrounded by a graphite reflector which, in turn, may be enclosed by boron, lead or water shielding. Critical assemblies and homogeneous solid reactors may have features of either a pool or a tank structure.

This classification is helpful for developing the typical facility inventory which is one part of input data for decommissioning costing. The above presented review shows the typical systems of research reactors, their material composition together with indication of main systems and structures contaminated or activated.

## CURRENT PRACTICE IN DECOMMISSIONING COSTING

### Current Approach and Costing Methodologies

Current experience in decommissioning costing was identified in several representative documents in the area [2], [8], [9]. Practical costing is carried out by identifying all work activities together with their associated material, equipment and service requirements. Subsequently, estimation is made of the costs arising from each elementary activity as the discrete and measurable elementary work activity for which unit costs are calculated or estimated - unit factors (costs, manpower, etc.) approach. If for some work activities only limited experience is available, preparing the cost estimate includes a phase by phase review of the required data and adequate engineering judgement is needed in order to assess manpower requirements, work efficiencies and time schedules. The representative features of decommissioning costing are listed below and will be implemented into the robust cost estimation methodology.

### Definition of Cost Categories

Within the proposed methodology, like in major decommissioning projects, costs are classified into following categories, depending on nature of decommissioning activities, methods of calculation of cost and types of main input variables:

- a) Activity-dependent costs, which are directly related to the extent of “hands-on” work involved in decommissioning. They include activities such as decontamination, removal of components, packaging, shipping and disposal of wastes, etc. Costs arise from labour, materials, energy, equipment and services. Main input variables determining the cost are the facility inventory data (mass of components of systems and structures, areas of building surfaces, volumes of waste, etc.), specific work factors related to individual types of systems and structures (normalised manpower unit factors or cost unit factors) and work difficulty factors reflecting the working conditions at the place of performing the decommissioning activity (increase factors).
- b) Period-dependent costs, which are proportional to the duration of individual activities or to the duration of the entire project. They arise from project management, administration, routine maintenance, radiological, environmental and industrial safety and security activities. These costs are often fairly independent of the exact level of the hands-on activities that is concurrently going on. Main input variables determining the cost is the duration of the activities and the composition of working group and their labour cost unit factors.
- c) Collateral costs and costs for special items which neither is assigned to a certain work activity nor to a period-dependent activity. Examples are equipments used to support many distinct activities, the purchase or the rent of these equipments. Typical character is the fixed cost allocated to a given date. Main input variables determining the cost are the list of equipment to be procured and list of payments.

- d) **Contingency** is the special cost item which is added to calculated cost elements in order to balance the specific provisions for unforeseeable elements of cost within the defined project scope, particularly important where previous experience relating to estimates and actual costs has shown that unforeseeable events that increase costs are likely to occur [8]. This cost item has special character, different for various decommissioning activities, and the level of contingency may be also different for various activities.

### **Identification of Decommissioning Activities for Hands-on Activities**

In the frame of the unit factors approach, the decommissioning plan must be developed in terms of discrete basic activities for which unit factors (manpower, costs, etc.) are defined. The list of activities is completed with a plant buildings and equipment inventory in order to define the full extent of each type of activity. Such an inventory should include all elements of systems and structures like pipes, valves, components of reactors, building surfaces, elements of civil structures, as an example. The interaction of the list of decommissioning activities with the facility inventories gives the required extent of calculation structure. As the result, the typical decommissioning activities related to systems and structures, like decontamination, dismantling, surveys, etc., are repeated through the calculation structure depending on the content of the inventory database. The prerequisite for this approach is the good facility inventory database.

### **Definition of Unit Factors**

Unit factors are defined in accordance to the details of the items considered in the plant inventory and in the list of activities of the decommissioning project. As an example, unit factors may be defined for cutting of normalised mass of pipe of a certain size (decommissioning category). This approach consists in developing the basic unit factors (cost, manpower, consumption of media, generation of secondary waste, etc.) for ideal conditions, e.g., cutting a non-contaminated pipe at a worker's waist height without any risk of radiation exposure and for local expenses related to labour per work hour, taking into account the different worker and craft categories. Various increase factors are considered for working height, need for protective equipment (respirators, protective clothing), accessibility of the working, dose rate levels (ALARA measures), work breaks and other productivity losses. The final value of a unit factors is corrected to include material and equipment costs proportional to the extent of work. Unit factors for waste management are defined per unit volume, mass, containers, etc. for each waste type.

### **Definition of Period-dependent Activities**

Based on the plant inventory and unit factors approach, the duration of individual work phases involving the hands-on activities in a decommissioning project is calculated. The relations and linking between individual tasks are defined which gives rise to identification of the duration of these activities. The overall project duration is defined by those activities that are on the critical path. An activity is considered to be on the critical path if start-up or continuation of other tasks depends on completion of this activity. As such, a time schedule may be produced for different phases of the decommissioning project as well as for the entire project. This schedule is then used as a basis for estimating of duration of period-dependent decommissioning activities for which the staff involved is defined. The management, administration and other supporting activities are typical for period-dependent activities. The relations between period-dependent activities and activity-dependent decommissioning activities are subject of optimisation by increasing the size of the crew for activities on the critical path (number of working groups, number of working shifts). When defining the staff for period dependent activities, the qualification of personnel is considered which differ in labour cost for different qualification stages.

### **Collateral Costs and Costs for Special Items**

Some costs may be dependent neither on the level of activities, nor on the duration of the project. The input data needed for calculation of these cost is mainly the lists of equipment to be procured for various purposes; lists of periodical payments like taxes, insurances, list of permanent payments during the accounting period for technical media, maintenance, surveillance, permanent services, etc.; list of specific

non periodical payments like permits, licences, external services, consultancies, etc. Specific items with this character of cost are negative cost; it means the incomes for scrap or reusable equipment where it is reasonable to consider.

### **Total Costs and Contingency**

At the end, the total cost estimate is obtained as a sum of the costs estimated in the three categories. The activity-dependent costs are calculated on the basis of activity lists, plant inventories, unit factors and increase factors; waste management cost are calculated based on volumes of individual types of waste and waste process unit factors. The period-dependent costs are calculated on the basis of project schedules and staff requirements, while the collateral costs are assessed separately for each item. The cost estimates are adjusted to include a contingency that reflects the level of uncertainty in the estimates (estimation of unforeseeable items, management of unknowns). For selected calculation items for which the cost can escalate significantly in the future, special items are identified in the standardised cost structure (items 11.0700 of the standardised cost structure). Allocation of reasoned contingency to individual calculation items or groups of calculation items belongs to the key steps in costing. As the result, the contingency may vary from 15 % for the removal of non contaminated equipment outside of the controlled area up to 75 % for dismantling of reactors [8].

### **Practical Aspects of Decommissioning Costing**

Decommissioning costing represents a set of manifold activities. Practical procedure in decommissioning costing, taken into account in the proposed costing methodology for research reactors, involves following principal steps:

#### **Preparation of Inventory Database**

The inventory database has three main components – the inventory of systems, the inventory of structures and radiological parameters. The systems and structures inventory normally refers to identification of the inventory item in the frame of building object - floor - room - equipment structure and to parameters like mass, surfaces, volume, categories of systems and structures, materials as the main data. The radiological parameters refer to contamination of inner and outer surfaces, induced radioactivity and dose rates in premises and in the vicinity of systems; all of them nuclide resolved if possible. The inventory items are prepared by reviewing the available facility documentation and based on inspection on site. The radiological parameters are measured directly on site or are calculated based on models of equipment and also by expert estimating of missing data. Special care has to be taken for calculation of the induced radioactivity of reactor construction materials.

#### **Preparation of the Database of Unit Factors**

The items of the database are unit factors and other data related to the individual decommissioning activities planned for the decommissioning project, like manpower unit factors, secondary waste production unit factors, material/media consumption unit factors, working group composition and its parameters (professions, labour costs, exposure parameters, etc.), structure of the working time, parameters of equipments for waste processing, radio-nuclide parameters, parameters of waste management, constants, correction factor, various technical - economical parameters, etc. Normally the data are prepared based on information from decommissioning projects completed, based on published data, or the data are taken from non-nuclear industry.

#### **Generation of Calculation Options**

The calculation options for the nuclear facility to be decommissioned are elaborated based on existing or planned decommissioning infrastructure and selected decommissioning strategy. The calculation options correspond with the activities presented in the decommissioning plan. The extent of calculation options should cover all relevant possibilities (considered immediate/deferred decommissioning options combined with various scenarios of waste treatment or default input data, etc.). The options are created

based on facility inventory database and extent of decommissioning activities intended in the frame of the calculation option.

### **Calculation and Optimization of Options and Selection of Optimal Option**

Each decommissioning option is calculated and optimised individually. The optimization represents the adjusting the time structure of the option and optimization of working groups and number or shifts for performing critical activities, adjusting the duration of period dependent activities, as an example. The optimization is in general the iterative process with more steps, each steps includes the adjusting of parameters, timing of the schedule, durations and recalculation/evaluation of calculated parameters. The aim of the end phase of decommissioning costing is the choice of the optimal calculation option from the set of calculated and optimized options for the nuclear facility. The recommended procedure for choice is the multi attribute analysis [10]. The input data for multi attribute analysis are calculated data for each option entering the analysis, completed with the subjective data delivered by the evaluators. The option with best characteristics is then taken as the option for decommissioning of the given nuclear facility and will be used for detailed planning of the decommissioning project.

### **APPROACH FOR COSTING MODEL FOR RESEARCH REACTORS**

The proposed costing model should consider all aspects of decommissioning strategy which have impact on cost. The details of the strategy are normally implemented into the decommissioning plan and the details of the plan should be involved into the costing model. Based on above discussed requirements for the costing and general experience in costing, the elements of the proposed parametric cost estimation system are identified as follows:

- a) Implementation of bottom up principle [2], it means calculation of cost and other decommissioning parameters at the level of discrete elementary decommissioning activities. Separate calculation items should be available for each elementary decommissioning activity, depending on the level of details of cost estimate.
- b) Flexible calculation structure, capable easy to include or exclude individual elementary decommissioning activities
- c) The calculation structure will be standardised, it means that it should involve the decommissioning activities as defined in [3] in order to enable the harmonisation in costing
- d) The calculation structure should correspond with the decommissioning plan, it means the calculated data should be produced for all decommissioning activities defined in the decommissioning plan of the project
- e) Implementation of costing procedure based on international experience
- f) The input data (facility inventory data, unit factors and other input data related to processes, personnel and other cost drivers) used for calculation should be organised in a well defined format which enable parameterisation of calculation model. At the same time the data should be easy adaptable to facility, site and national specific situation related to decommissioning
- g) The formats of calculated data should meet the requirement for harmonisation in costing
- h) Multi option approach for supporting the decision making process should be feasible

### **Characteristics of the Costing Model**

Items “a” to “c” define the main requirements for the calculation structure which ensure the calculation of data at the lowest elementary level; the flexibility and standardisation of the structure. The optimal way how to implement these requirements is the use the structure of [3] directly as the calculation core. By introducing the proper methods of management of the calculation structure in order to fit the calculation structure to individual decommissioning projects, it can be achieved that this structure can be implemented as the calculation core into any decommissioning project. The calculation structure is then standardised for all calculation cases and the extent of individual calculation cases can be easily defined.

Item “d” defines the relation of the standardised calculation structure to the structure of the decommissioning work breakdown structure (WBS) of the given decommissioning case. The WBS structure is specific for the given decommissioning case and reflects the extent and fine structure of decommissioning activities, mutual links of activities and distribution of activities in time. Thus the WBS represents the specifics of the decommissioning project while the calculation structure keeps its universal structure for all decommissioning cases. In order to achieve this two contradictory requirements, the unambiguous links should be defined between the standardised calculation structure and the decommissioning WBS for the given calculation case. The items of the calculation structure can be linked to items of the WBS as one-to-one links or the items of the calculation structure can be grouped to create one item of the WBS. This approach enables to preserve the manageability of the WBS (not too much items for defining the time structure and mutual links) and at the same time to have as much of the calculation items as needed.

Item “e” means that the international experience in decommissioning costing will be implemented, see chapter 4.

Item “f” is one of key challenges for the costing model in order to achieve the features of the parametric costing model. The calculation methodology should be adjusted so that it uses the selected key input parameters for all calculation options of the case and set of input data specific for individual calculation options. In this way the parametric cost system can be developed for any decommissioning case. The selection of the set of key input parameters should be balanced regarding the level of details of cost estimation. The key input data are selected from the group of inventory data, unit factors data, personnel data and other input data specific for the facility.

Item “g” refers to formats of calculated data which is also one of the key aspects of harmonisation in costing. The standardised formats of calculated data can be developed by two ways – to reshuffle the data calculated in various structures into the standardised format (general approach for calculation codes which do not implement the standardised structure of [3]) or the direct presentation of the data calculated in the standardised calculation structure. The second principle is the straightforward one and does not require any additional data processing which may cause additional inaccuracies.

Item “h” represents the multi option approach [10] which is easy to implement when having the parameterised calculation structure is available with data links to common modules with the key input data relevant for all calculation cases to be evaluated for the given decommissioning case.

## **PRINCIPLES OF IMPLEMENTATION OF THE STANDARDISED COST STRUCTURE**

### **Decommissioning Activities for Research Reactors**

One of the key aspects of decommissioning costing is the identification of all relevant activities for the given decommissioning project. The review of decommissioning activities, its classification from the point of view of character of activities, specifics of these activities related to research reactors, relation of the identified elementary decommissioning activities to the structure of the standardised list of decommissioning activities and the relation of the activities will be developed.

The methodology on how to prepare the inventory of decommissioning activities for decommissioning costing for individual decommissioning project will be developed. Except the D&D activities that could have general character depending on the type of the reactor, the important role in decommissioning of research reactor have the waste management technologies – the availability of individual technologies, the extent of technologies in order to cover all types of waste generated during decommissioning and the final solutions as the disposal or releasing of materials. In some cases the long term storing of waste is the final solution from the point of view of the decommissioning project.

The general principle of estimating the decommissioning cost in the proposed methodology is the “activity based costing”, which is based on evaluation of elementary decommissioning activities. The



most important issue of this approach is the proper identification of all activities involved in the decommissioning project. In the case of hands-on activities, the extent of activities to be evaluated is developed based on interaction of the set of identified typical activities with the facility inventory. In the case of period dependent activities and fixed cost, the extent of calculation items is developed as the facility specific file which is related to the structure of hands-on activities.

The character and extent of decommissioning activities considered in the proposed methodology, corresponds to decommissioning of small and medium nuclear facilities of research reactor type. Decommissioning activities of a decommissioning project are normally presented in the decommissioning plan. The decommissioning plan is the right place where the types and specific reasons for selecting the decommissioning activities are discussed and reasoned, depending on the characteristics of the facility and local site facility conditions.

The extent of decommissioning activities depends on the strategy of decommissioning selected which includes also definition of the end state. Large variety of strategies and end states is identified in decommissioning of research reactors [1], [7], [11]. Some strategies are immediate dismantling with the green field end state or specific end state with radioactivity content at site according the limits defined by national legislative. For strategies with the character of differed dismantling, various end states may be selected. In the case of research reactors also the entombment strategies are considered.

This implies the fact, that the structure of decommissioning activities for research reactors may be very manifold. The decommissioning activities for research reactors in “full” extent will be identified for decommissioning case with implementation of immediate strategy and for deferred strategies. The identified activities will be classified according the standardised list of cost items [3]. The classified activities will be the base for implementation of the standardised structure for the standardised costing model for research reactors.

### **Implementation of the Standardised List of Cost Items**

The decommissioning activities as defined for a decommissioning project will be classified in the calculation structure according the standardised cost structure [3] (the abbreviation **PSL** is used for [3] – **P**roposed **S**tandardised **L**ist) which is defined as a system of types of decommissioning activities arranged in 11 classes as follows:

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

The standardised structure was developed as a hierarchical structure numbered down to the third level. From this level down, typical activities are only listed, not numbered. For any user, it is possible to add additional levels. Implementation of the bottom up principle means the calculation at the lowest level of identified elementary decommissioning activities. The implementation of PSL structure means the configuration of decommissioning activities according the PSL numbers. Principles of organisation of the decommissioning activities in the PSL structure are following:

- a) Level “10” - eleven classes are defined numbered as 01 to 11

- b) Level “100” - sub groups are defined numbered in steps of 100
- c) Level “1000” - specific activities are defined with the step of 1

An example of the hierarchical structure of standardised decommissioning activities is following:

04 Dismantling activities

04.1300 Removal of primary and auxiliary systems

04.1301 Removal of primary and auxiliary systems in reactor facilities

04.1302 Dismantling and removal of contaminated equipment, piping, liners and internal systems in non-reactor nuclear facilities

The standardised structure, as defined, is the unique platform for harmonisation of decommissioning costing, at least for presenting the cost for decommissioning. The meaning of implementation of items of the standardised structure is the obligatory use of the numbered levels and the openness of the standardised structure for additional project specific definitions of decommissioning activities down from the last (third) numbered level, as it can be seen from the example above. This approach “fixed on top, open downwards” brings the possibilities of implementation of the standardised structure in principle for any nuclear facility. It means that the nuclear facilities of various types could have its own specific spectrum of decommissioning activities. This could be one of the subjects of harmonisation - to develop the detailed structure of standardised items for typical nuclear facilities. The research reactors as defined in this document, it means the small and medium nuclear facilities, could have its own detailed standardised cost structures, at least for main types of research reactors. The base for numbering of PSL levels are the three above listed numbered PSL levels. These levels are proposed to be extended using the principle of extension according the groups of two digits [12] following:

PSL level “1000.xx”            04.1301.01  
PSL level “1000.xx.xx”        04.1301.01.01  
PSL level “1000.xx.xx.xx”    04.1301.01.01.01  
Etc.

The additional PSL numbering below the three numbered levels is open downwards for the users. The group of two digits creates enough space for identifying the specifics within any group; it is possible to define 100 numbered subgroups at each level and when needed other subgroups can be defined. This approach has following advantages:

- a) Common standardised calculation platform is established which is harmonised to the third numbered level for any calculation case
- b) Any aspects which are specific for a group of nuclear facilities can be easily harmonised at the lower calculation levels. This is for example the case of research reactors as defined within this project; it means small and medium nuclear facilities.
- c) There are additional possibilities for development of calculation structures for typical equipment with complex constructions like calculation structures for dismantling of reactors of a given type. In this way, the calculation segments can be developed which can be easy to implement into any standardised calculation structure.
- d) There is no limitation in numbering the levels downwards. There could be some practical limitations for the level of details of a decommissioning project and limitations of the software used for the calculation structure. There are some limitations for the spreadsheets software Excel, but practically no limitation for ORACLE.

Implementation of these principles have a principal impact on decommissioning costing in general and also for partial programmes like the methodology for costing of research reactors. When similar approach is accepted also for other groups of nuclear facilities, the harmonisation in decommissioning costing could precede a big step forward. The costing procedures in this way could be harmonised and at the

same time they could remain specific for selected branches of nuclear facilities. A kind of database of specific calculation structures could be developed which can be one of the contributions of the project to harmonisation in decommissioning costing. As an example, the calculation structures specific for dismantling procedure for different types of research reactors will be proposed in the frame of this project.

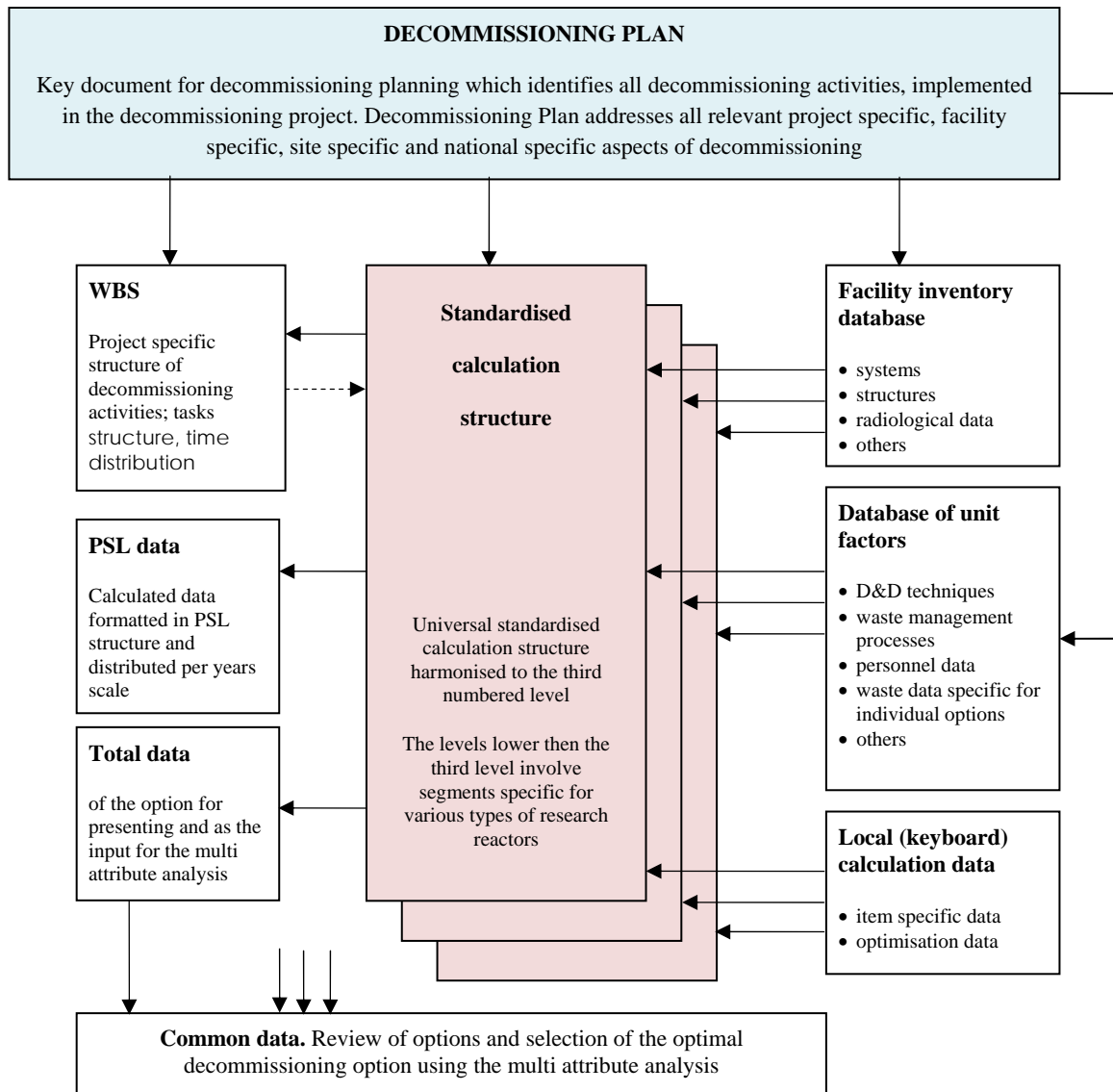
Cost groups are defined for each calculated item: labour costs (12.0100), capital, equipment and material costs (12.0200), expenses (12.0300) and contingency (12.0400). This brings additional possibilities for comparing the cost.

## **STANDARDISED PARAMETRIC COST ESTIMATION MODEL FOR RESEARCH REACTORS**

### **Implementation of the Costing Approach**

The principal scheme of implementation of the proposed approach for standardised costing in research reactors in the IAEA project is presented on Figure 1. The principles of implementation of the standardised cost structure, as presented in chapter 6.2, and also the principles of the parameterised costing model were already implemented and verified in [12], [13]. The experience collected will be used in this IAEA project for robust cost estimation methodology for research reactors.

Fig.1 Principal scheme of the standardised costing model for research reactors



The characteristics of the modules presented in the principal scheme are following:

- a) Standardised cost calculation structure which implements the classification of decommissioning activities according [3]. Depending on the level of details, the calculation of cost is performed at the lowest level of the structure. The calculated data are formatted directly in the standardised structure [3].
- b) WBS – Work Breakdown Structure of decommissioning tasks, represents the sequence of individual tasks as defined in the decommissioning plan. The calculated data for the WBS are taken from the standardised calculation structure based on grouping and/or linking of items of the calculation structure to the tasks of WBS.
- c) Facility inventory database. Contains all data of systems and structures needed for calculation of cost and other decommissioning data. The optimal structure is the building object – floor – room – database item (components of systems, items of building surface, items of structures)
- d) Database of unit factors. Contains the unit factors for techniques and processes, personnel data and other data defined as common data for calculation of cost and other decommissioning parameters and the waste data as pre-calculated input values (masses, volumes, pieces, etc.) of individual waste types

according to the types of waste. The types of waste correspond to scenarios for applied for individual decommissioning options.

- e) Local input calculation data - input data which are specific to individual calculation items; the data are introduced to the calculation structure as the keyboard data. The calculation code should have the possibility to introduce these data into individual calculation item of the calculation structure.
- f) PSL data - calculated data formatted in PSL structure. The data calculated at the lowest hierarchical level of the calculation structure are grouped at higher PSL numbers up to the level "PSL 10".
- g) Total data - the data for the option for presenting the overall parameters of the case. The cost data are also processed to create the distribution of cost per years of the duration of the decommissioning project.
- h) Common data – data for procedures which uses the multi attributes analysis for selecting the optimal decommissioning option.

### **Cost Calculation Procedure**

The experience from current decommissioning costing shows that the straightforward methodology for calculation of cost is the calculation of manpower components of individual elementary decommissioning activities at the first step. The manpower components can be then assigned to individual professions which participate on performing of the elementary decommissioning activity according to the composition of the working group. The manpower components for individual professions of the working group are calculated as components proportional to number of workers for individual professions within the working group. These manpower components related to individual professions are the base for calculation of labour cost for individual elementary decommissioning activities. The costs are completed by investment cost and by expenses processes involved in the elementary decommissioning activities and at the end completed by contingency. Calculation of manpower is different for hands-on (activity-dependent) activities, for waste management activities and for period dependent activities.

Manpower for activity-dependent decommissioning activities is calculated as the product of input inventory variable (mass, surface, volume, ...) and the manpower unit factor for the individual decommissioning category. Dismantling of 1 tone of pipe of the given category, or decontamination of 1 m<sup>2</sup> of the building surface by chemical decontamination are the examples. Manpower components are increased in calculation for non-productive time components defined for in or outside of the controlled area and additional manpower is calculated were relevant, using the increase factors due to work in radiation fields, work in heights, remote controlled techniques, etc.

Principle of categorisation of systems and structures proved to be effective in calculation of cost for activity dependent cost. The size, construction and material composition gives rise to different unit factors for different equipment to be dismantled. The unit factors are similar for equipment with similar properties and can be very different for equipment with different constructions. Another aspect in implementation the principle of categorisation is the selection of relevant decommissioning technique for the given category. The various techniques have different properties and the consequences in decommissioning costing are different unit factors for various techniques. The selection of the optimal decommissioning technique for the given decommissioning category is the very important issue in decommissioning costing. The decommissioning category is one of the key parameters in decommissioning costing. This approach enables to reduce markedly the volume of data needed for decommissioning costing.

Manpower for period-dependent activities is calculated as the sum of manpower components calculated as the product of duration and number of personnel for individual professions. This procedure is used also for calculation of manpower for waste management activities, where the duration is calculated as the product of capacity of the given technological unit and the input variable which is the amount of input waste to be processed.

## **ACTIVITIES PROPOSED FOR THE PROJECT**

The objective of the project is to provide the basic knowledge on costing methodology and to develop the robust standardised cost estimation methodology for research reactors of various types. The methodology should cover all aspects starting from collecting the data needed for costing, through developing the calculation cases, calculation and optimisation of cases, up to final formatting of the calculated data. The extent of activities proposed for development of the standardised costing methodology for research reactors cover following issues:

- Review of aspects of decommissioning for various types of reactors;
- Development of the practical costing methodology for research reactors;
- Inventory database for research reactors;
- Database of unit factors and other calculation data;
- Standardised cost calculation structure for research reactors;
- Extent of calculated data;
- Calculation procedures for calculation of cost and other decommissioning parameters;
- Formats and processing of calculated data
- Software for supporting the costing of research reactors

### **Review of Aspects of Decommissioning for Various Types of Research Reactors**

The objective is to develop the classification of research reactors from the point of view of decommissioning. The subject of the task will be the classification of research reactors according the construction types, materials, size. This classification will help to develop the inventory data and the cost calculation structure (typical dismantling procedures). Typical structure of decommissioning activities for individual types of research reactors will be identified based on information available. The collected data will be analysed and the data will be used for completing the model inventory databases and for completing the typical decommissioning activities of research reactors.

### **Development of the Practical Costing Methodology for Research Reactors**

The proposed costing methodology is the implementation of the standardised cost calculation structure [3] as the base of the harmonised calculation core and implementation of the general international experience in decommissioning costing as presented in chapter 4 of this paper. The proposed calculation methodology implements the basic cost categories – hands on activities, period dependent activities, collateral costs and adjustment of total cost by contingencies. The individual steps for performing of practical decommissioning costing will be defined which include the development of input data for the facility (inventory database and database of unit factors), developing the standardised calculation case, calculation of the data, optimising the calculation case and formatting the calculated data in standardised formats.

### **Inventory Database**

The general structure of the inventory database for decommissioning costing should be proposed which will be applicable for all stages of costing of research reactors in accordance with the agreed costing approach. The extent of data in the database structure should cover all main types of research reactors. The recommended structure is the universal hierarchical structure which follows the structure of building objects, floors, rooms (cells) and systems, surfaces and structures items in the room. The calculation items for activity dependent cost will be derived from the content of the inventory database. The data will cover the identification, localisation, physical, radiological data as the standard data in the inventory databases and decommissioning data with relations to categorisation of inventory database items and in relation for application of standardised cost structure [3]. The list of decommissioning categories for inventory items of systems, building surfaces and civil structures will be developed for applications for the types of research identified for the project.

### **Database of Unit Factors and Other Calculation Data**

As the first step for development of the database of unit factors, the D&D decommissioning techniques for research reactors will be systemised in accordance with the list of decommissioning categories. Typical waste management scenarios and typical waste items for decommissioning of research reactors will be reviewed and the list of typical waste management techniques for applications for research reactors will be elaborated. Data sheets for individual D&D and waste management techniques will be elaborated. The data will include the manpower unit factors, cost factors, media and material consumption unit factors, working group data, secondary waste generation factors and other data. The ranges of waste amounts as the input data for individual waste management techniques for various types of research reactors will be identified or estimated.

### **Standardised Cost Calculation Structure for Research Reactors**

Based on the proposed approach, which foresees the implementation of the standardised cost structure [3] for costing of research reactors, the template of standardised cost calculation structure will be developed with application for types of research reactors identified for the project. The template will be used for development of the harmonised standardised calculation structure for individual cost estimation cases. The template will cover the typical decommissioning activities identified for individual types of research reactors. The template will be developed as the general structure which will have three numbered levels as defined in [3] and the level lower to these numbered levels will be specific for research reactors and will involve the segments of the standardised cost calculation structure applicable for all types of research reactors involved. This approach is in line with the effort of IAEA for promotion of harmonisation in decommissioning.

### **Extent of Calculated Data**

Extent of calculated data (cost, manpower, exposure, etc.) will be defined corresponding to the level of robust cost calculation for the research reactors. The generation of the decommissioning schedules and the data for decommissioning schedules will be discussed and the procedure will be developed.

### **Calculation Procedures for Calculation of Cost and Other Decommissioning Parameters**

The task covers the development of costing procedures for the robust standardised costing of research reactors. The methodology proposed will be based on calculation of manpower for hand-on activities using the principle of categorisation of systems and structures and calculation of manpower for period dependent activities based on definition of duration of activities and staff for activities.

### **Formats and Processing of Calculated Data**

The task will cover the format of cost data and other calculated decommissioning data. At least following formats will be discussed - the PSL format, the cost data in form of a time graphs and the data linked to the decommissioning schedule. Formatting the data in PSL format will support the development of the common platform for management of calculated cost data like contingency adjustment, risk management and other procedures for data processing.

### **Software for Supporting the Costing of Research Reactors**

The easy to use software for promotion of standardised decommissioning costing will be discussed and proposed. Currently, the Excel software seems to be the optimal solution due to world wide use and relatively simple requirements for use.

## **CONCLUSIONS**

Involvement of the IAEA in decommissioning costing for research reactors reflects its position in supporting the member states in specific area of decommissioning costing. Main objective of the new IAEA project for the period of 2009 - 2011 is to summarize the current international experience in decommissioning costing and to adapt it for the purpose of robust decommissioning costing methodology for research reactors. The idea is to support the IAEA Member States in preparing their own

decommissioning costing which reflects the specifics of facilities, sites and the national background in decommissioning.

The robust costing methodology should implement the standardised cost structure [3] which is recommended for use by the IAEA and other international organisations involved in decommissioning – the OECD/NEA and the European Commission. The proposed robust costing methodology implements the standardised structure in full extent by using it as the calculation structure. The segments of the standardised structure specific for decommissioning of research reactors will be developed. The proposed method of implementation of the standardised structure is in line with the current trends in standardised costing.

The activities of the tasks related to implementation of the standardised cost calculation structure and for formatting and management of calculated cost will be coordinated with the current activities of the Decommissioning Cost Estimation Group of the OECD/NEA which is currently the main representative international activity in the area of standardised decommissioning costing. It involves the upgrading of the standardised cost calculation structure as defined in [3] as the interim technical document and also methods for processing of calculated cost.

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