IAEA Nuclear Energy Series

No. NW-T-2.4

Cost Estimation for Research Reactor Decommissioning

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA NUCLEAR ENERGY SERIES No. NW-T-2.4

COST ESTIMATION FOR RESEARCH REACTOR DECOMMISSIONING

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2013

Printed by the IAEA in Austria
November 2013
STI/PUB/1596

IAEA Library Cataloguing in Publication Data

Cost estimation for research reactor decommissioning. — Vienna : International Atomic Energy Agency, 2013.
p. ; 30 cm. — (IAEA nuclear energy series, ISSN 1995–7807 ; no. NW-T-2.4)
STI/PUB/1596
ISBN 978–92–0–140210–3
Includes bibliographical references.

1. Nuclear reactors — Decommissioning. 2. Nuclear reactors — Costs. 3. Nuclear reactors — Computer programs. I. International Atomic Energy Agency. II. Series.

IAEAL 13–00869

FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property." The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

The purpose of this publication is to develop a costing methodology and a software tool in order to support cost estimation for research reactor decommissioning. The costing methodology is intended for the preliminary cost estimation stages for research reactor decommissioning with limited inventory data and other input data available. Existing experience in decommissioning costing is considered.

As the basis for the cost calculation structure, the costing model uses the International Structure for Decommissioning Costing (ISDC) that is recommended by the IAEA, the Organisation for Economic Co-operation and Development/Nuclear Energy Agency, and the European Commission as the general platform for decommissioning cost estimation purposes. Use of the ISDC based model facilitates the preliminary costing stages in the absence of decommissioning plans. For proper establishment of the costing case, the intended decommissioning strategy is used. The model should be flexible as to the extent and details of the inventory data. The impact of individual inventory items (working constraints) should be respected. Implementing the ISDC as the basis for the cost calculation structure ensures compatibility with the IAEA classification scheme for radioactive waste.

The developed tool is intended for experts who are familiar with the facility, such as the former or actual operators of research reactors. A basic knowledge of decommissioning issues is recommended.

The IAEA officers responsible for this publication were M. Laraia and V. Michal of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

1. INTRODUCTION

The activities of the IAEA involve the whole spectrum of nuclear facilities and cover all aspects of decommissioning. The decommissioning of non-power-generating facilities such as research reactors, owing to their worldwide distribution among Member States, is of special importance in IAEA activities. The experience of research reactor decommissioning has been gained most prominently in countries with more advanced nuclear programmes, and therefore international activities are required to support planning and implementation for the decommissioning of research reactors outside developed countries. Among these issues rests the aspect of decommissioning costing.

The cost aspects of decommissioning facilities that have used radioactive material became a serious issue in the mid-1980s, when the nuclear power industry in some countries experienced severe cost overruns and financial problems. Estimates of the cost of decommissioning these large nuclear power plants quickly escalated in some Member States, driven by the rapidly increasing costs of radioactive waste disposal and the limited number of facilities licensed to receive this waste. Even in countries enjoying a more favourable waste management infrastructure, more accurate estimates of decommissioning costs were required by the growing maturity of the nuclear industry [1].

Up to the present time, aspects of decommissioning costing were addressed mostly from the points of view of cost structure and compatibility of cost elements in different decommissioning projects, identification of representative values for individual cost categories, systems for collecting relevant funds for decommissioning and analysis of uncertainties and contingencies for decommissioning costs.

The procedures for decommissioning costing were presented mostly as isolated cases without any broader analysis. Documents were available where the principles of individual decommissioning costing methods were reviewed. The methodologies were developed by companies that were involved in decommissioning costing in the long term, and the methodologies were based on actual experience gained in decommissioning. Other methodologies and codes were developed in specialized research projects funded by governments or by the private sector. The details of most of the costing methodologies and tools were not made available owing to companies wishing to preserve their intellectual property and hence commercial advantage. This is one of the most important findings of several projects regarding dissemination of information.

The cost of decommissioning is generally restricted to national and site specific bases. Approximations from other facilities are usually inappropriate to use as a basis to establish funding. The involved parties, such as the owners/licensees, the regulators and the public, need to agree upon the detailed site specific estimates of cost. The methodology for estimating the costs of decommissioning have evolved over approximately the last 30 years, from simple ratios of the costs to decommission earlier smaller facilities, to detailed ‘bottom-up’ estimates where detailed inventories of equipment and structures are analysed and estimated for decontamination, removal, packaging, transportation and disposal.

A clear move from approximate approaches to sophisticated analytical solutions in decommissioning costing was identified. Many advanced methodologies and computer codes were developed for evaluation of decommissioning costs and for the evaluation of contingencies and uncertainties of cost in order to increase the accuracy of the total decommissioning costs and their structure. As the decommissioning of nuclear facilities became a serious activity for the industry, the financial assurance of decommissioning required reliable data on costs.

Another important aspect of decommissioning costing is the harmonization of decommissioning costs in order to be able to compare them and to develop a uniform approach to decommissioning costing. The broad spectrum of facilities to be decommissioned, from power and research reactors to small research laboratories, created a challenge to develop a common platform for harmonization. Serious differences were identified in costs for comparable decommissioning projects [2]. The reasons could be clarified only after the identification of the main cost drivers and the decommissioning activities where the costs arose.

The logical step for this effort was the establishment of a common platform for the identification of decommissioning activities, which was developed as a comprehensive structure involving all decommissioning activities applicable for the decommissioning of any nuclear facility. This base for harmonization in decommissioning costing was introduced for general use in the publication A Proposed Standardised List of Items for Costing Purposes in the Decommissioning of Nuclear Installations, issued jointly by the IAEA, the Organisation for

Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA) and the European Commission (EC) in 1999 [3]. The structure was upgraded by the same organizations in 2012 as the International Structure for Decommissioning Costing (ISDC) [4].

Experience in decommissioning costing was gained in industrial countries, especially for large nuclear facilities such as nuclear power plants. The methodologies developed were also used for costing small facilities of the size of research reactors. However, these costing methodologies remain within the expertise of companies specializing in decommissioning costing. Another feature of these costing methodologies is the relatively high level of detail. Use of these methodologies requires skilled personnel.

Research reactors are spread worldwide; the range of different types of reactor is large, varying from the size and complexity of power reactors down to small facilities on a laboratory scale such as critical assemblies. Many of the research reactors are nearing shutdown or have already been shut down. A relatively simple costing methodology is required for preliminary costing that is applicable for various types of research reactor. The purpose of the costing methodology presented in this publication is to develop a relatively simple costing model that can be used mostly by operating personnel of research reactors. Limited experience in decommissioning planning and costing is expected of these personnel.

The simplified costing methodology should be able to provide preliminary cost data to identify the nature of the funds or budget for decommissioning. The structure and levels of detail of input data for the costing methodology are expected to be manageable by the operating personnel for research reactors. The ISDC was selected as the base for the costing model for research reactors for several reasons:

— The ISDC involves all typical decommissioning activities for any nuclear installation;
— A description of ISDC items and a supporting manual are available;
— The ISDC may be used at the preliminary costing stages without a decommissioning plan;
— Its use is in line with IAEA efforts in promoting harmonization in decommissioning costing.

2. SCOPE

Costing and funding issues were addressed specifically by the main international organizations involved in decommissioning: IAEA [1], OECD/NEA and EC [3, 4]. One of the most important results of this common effort is the standardized cost structure of decommissioning cost items. This structure can now be identified as the common platform for harmonization in decommissioning costing.

The activities of the EC and OECD/NEA are oriented mostly to power generating facilities owing to the fact that huge amounts of finance will be required for decommissioning projects in the near future, and the finance should be adequately provisioned and appropriately planned. Experience in decommissioning has already been accumulated, and decommissioning is now an established nuclear industry activity. This is a positive aspect, but there is also a negative aspect inasmuch as the information on cost estimation methodologies and representative data are increasingly the subject of companies' expertise, and less information and data are openly available owing to commercial competition in the decommissioning market.

The decision to develop this publication corresponds to the continuous efforts of the IAEA in supporting decommissioning costing in Member States. The publication is the logical continuation of a series of publications prepared by the IAEA in this area:

— Decommissioning costing and funding [1, 3, 4];
— Technical aspects of decommissioning [5–7];
— General aspects of decommissioning, including strategy, planning and resources [8–11].

A User's Manual for Costing Software for Research Reactor Decommissioning (CERREX — Cost Estimate for Research Reactor in Excel) has been developed with assistance from the IAEA, and the software itself is on the attached CD-ROM.

3. OBJECTIVE

The main objective of this publication is to develop a general methodology and tool for preliminary cost estimating for research reactors. Each decommissioning project should involve a cost estimation that is facility specific and accommodates the national decommissioning background by considering the specific features of legislation, regulation, decommissioning strategy and waste management.

For these purposes, a general cost estimation methodology is required, which should be applicable for various types of research reactor. It is the intention to prepare a methodology for the preliminary costing stage, where the input data and extent of the materials inventory are limited. Furthermore, the costing model is intended mainly for application by former or currently active operators of research reactors who are familiar with the facility and the basic aspects of decommissioning.

The proposed methodology should support the Member States to develop their national, site and facility specific cost estimates for research reactors.

4. STRUCTURE

In Section 5, the publication reviews briefly the basic types of research reactor, construction types and main constructional materials.

Section 6 presents aspects of current decommissioning costing methodologies such as the purpose of decommissioning costing, approaches in decommissioning costing, principles of current costing methodologies, practical aspects of costing and structure of calculated costs, and reviews some of the latest approaches in costing methodologies. Experience in decommissioning costing is also presented in Section 6, and is one of the sources for development of the costing model for research reactors.

Section 7 deals with types of decommissioning activity in general: activities for preparation for decommissioning, decontamination and dismantling, waste management activities, site restoration and release, management and support activities, spent fuel management and other decommissioning activities. Specific characteristics of decommissioning activities related to research reactors are presented. The ISDC, which plays a key role in harmonization of costs (its structure, content of items and methods of implementation) is presented. Some methods for identification of decommissioning activities for costing are presented.

The quality and structure of input data for decommissioning costing also play key roles in decommissioning costing. These data, and methods for their collection, are discussed in Section 8: the facility inventory database, its purpose and structure (radiological, physical, identification and specific decommissioning data); unit factors related to processes; input data related to personnel; waste data; and other input data.

Section 9 presents the costing approach based on the ISDC: the general costing model, costing procedures specific for using the ISDC as the cost calculation structure and formats for the calculated data. Grading aspects in costing are also discussed.

Implementation of the proposed approach for using the ISDC as the cost calculation structure for costing of research reactors is presented and discussed in Section 10 and Conclusions in Section 11. The background for the costing model for research reactors is presented, together with the implementation of the ISDC into the costing model for research reactors, the level of detail, input data and some practical aspects of the model.

Appendix I presents the ISDC structure to the extent of numbered ISDC items, Appendix II presents the schemes for cost calculation methodology and Appendix III presents the basic types of calculation algorithm.

Appendices IV–VI deal with the application of CERREX software.

5. REVIEW OF RESEARCH REACTORS

5.1. UTILIZATION 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. Many universities and government institutes use these facilities for conducting basic research programmes. In other cases, irradiation of samples may be performed as a service to other organizations on a fee basis. There are many different types of reactor, 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 to a complexity comparable with power reactors.

Critical assemblies are used for various research programmes and physics studies. They are a rather minor problem when it comes to decommissioning. Typically, activation levels are fairly low and pose a very minor risk to workers performing the decommissioning activities [12].

A large number of research reactors remain operational, but more appear to be approaching shutdown and implementation of the decommissioning process. This is a result of the decline in overall operational funding, and the use of these facilities has decreased dramatically over the last few years [12]. Although some new research reactors are still being planned and constructed, in many developed countries, their use is decreasing. Some programmes in developing countries do continue to move forward using existing or recently constructed facilities.

It is assumed that a typical operational period for research reactors and critical assemblies is 40 years, with a typical decommissioning time of 3 years for research reactors and 1 year for critical assemblies. In some cases, a period of 45 or 50 years has been assumed to take account of some of the very old research reactors that still have not been permanently shut down.

5.2. TYPES OF RESEARCH REACTOR CONSTRUCTION

The construction of research reactors varies to a large extent. Relatively simple constructions of critical assemblies can be located within a larger laboratory room. Medium size research reactors have a compact construction (mostly embedded in a concrete monolithic structure) located within a single building with a reactor hall and some additional rooms for auxiliary systems. The research reactors at the highest power range have constructions similar to power reactors: a reactor building with a reactor hall, many additional cells for primary, secondary and auxiliary systems and several additional buildings including ones for treatment of operational wastes. Different methods can be used to classify research reactors [6]:

— Power level: From zero power to hundreds of megawatts.
— Utilization: Education, training, research, materials testing, isotope production, prototype, etc.
— Moderator type: Light water, heavy water, graphite, etc.
— Decommissioning perspective: Classification of research reactors according to their structure and materials in relation to an applicable decommissioning procedure.

In particular, decommissioning aspects such as radionuclide inventory, decontamination and dismantling techniques, waste activities and volumes can readily be discussed using the following classification: pool reactors, including TRIGA and SLOWPOKE; tank reactors, including heavy water and the Argonne Nuclear Assembly for University Training (ARGONAUT); homogeneous liquid reactors; fast reactors; graphite reactors; and other reactors, including critical assemblies, homogeneous solid reactors and others. The following brief review is based on data from Ref. [6].

5.2.1. Pool reactors, including TRIGA and SLOWPOKE

Pool reactors are characterized by a reactor core submerged in a pool of water that usually provides cooling, moderation and shielding. The reactor may also be equipped with a specific moderator or reflector (e.g. graphite or beryllium). The continuous rated 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 (although 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. Pool reactors utilize a wide variety of fuels, including metal plate, oxide and a homogeneous mix of partially enriched uranium in zirconium hydroxide, as in TRIGA reactors.

5.2.2. Tank reactors, including heavy water and ARGONAUT

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 megawatts. The cooling systems are mainly of the closed circuit type. The complexity of primary and auxiliary systems of reactors in the highest power range is similar to power reactors in the range of hundreds of megawatts.

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.

The ARGONAUT reactors 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. Commercial versions were initially rated at 10 kW and later upgraded to power levels of about 100 kW.

5.2.3. Homogeneous liquid reactors

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.

5.2.4. Fast reactors

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, owing to the lower percentage of thermal neutrons in the core.

5.2.5. Graphite reactors

In graphite reactors, graphite blocks serve as the moderator, as well as being the main components of the core structure. The fuel rods are inserted among or within the graphite blocks, and the coolant, if required, is generally gas (usually air or carbon dioxide), but may sometimes be water.

5.2.6. Others

This category comprises all those reactors not covered in the previous sections. In particular, this group includes 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. As a result of this, the radionuclide inventory is low, and no significant hazard or technical complication is involved in decommissioning. Homogeneous solid reactors generally have 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 that, 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.

6. APPROACHES IN DECOMMISSIONING COSTING

6.1. PURPOSE OF DECOMMISSIONING COSTING

The estimating of costs and other decommissioning parameters is one of the main issues in the preparatory phases of decommissioning. Reliable cost estimating is one of the most important elements of decommissioning planning. Alternative decommissioning options (decommissioning techniques, waste management, end states, etc.) are recommended to be evaluated and compared, based on their efficiency and effectiveness and measured against a baseline cost as to the feasibility and benefits derived from the technology. When the plan is complete, these cost considerations ensure that it is economically sound and practical for funding [1].

The main aim of these activities is to prepare files of qualified data (costs, workforce, exposure, volumes of waste, personnel requirements, consumption items, equipment required for performing the decommissioning activities, etc.). On the basis of this qualified data, the decommissioning process can be planned:

- Safely, with minimal actual and future impact on personnel, the public and the environment;
- Economically, according to a cost optimized option for decommissioning;
- To schedule, according to a time and resource optimized option for decommissioning;
- To be publicly acceptable, by agreement of the involved parties.

The selected option for decommissioning should be the result of an evaluation of a set of options covering all scenarios taken into consideration. For selection of an option, the methods of multiattribute analysis may be used. It is assumed that each option is optimized individually before entering the multiattribute analysis.

The decommissioning cost estimation should include all activities, starting from planning for decommissioning, the transition phase (from shutdown to decommissioning), performing the decontamination and dismantling and management of the resulting waste, up to the final remediation of the site. All supporting activities, such as management of the project, maintenance, surveillance, physical protection, research and development, etc., should be included. The decommissioning plan [10], which includes all relevant decommissioning activities, is the inevitable prerequisite for a reliable estimation of decommissioning costs.

Estimates of decommissioning costs have been performed and published by many organizations. The results of an estimate may differ [2] because of different work scopes, different labour force costs, different monetary values due to inflation, different oversight costs, the specific contaminated material involved, the waste stream and peripheral costs associated with that type of waste, or applicable environmental compliance requirements. A reasonable degree of reliability and accuracy can only be achieved by developing decommissioning cost estimates on a case by case, facility specific basis.

Decommissioning costing methodologies were developed based on experience gained from actual decommissioning. The developed methodologies were then used for similar facilities, after adjustment of unit factors and other elements of cost methodologies for differences in facility size and inventory, and local and other factors. The quality of results of calculations depends on the quality of the adjustment of the unit factors for differences in facilities and on involving all relevant decommissioning activities. If there are significant differences in facility size, inventory or radiological situation, differences in cost estimates may occur.

The recommendation of how to overcome these drawbacks is to use the facility specific approach that identifies and evaluates the activities of a decommissioning project at the lowest level of detail available, relevant to the level of the project (starting from the conceptual plan, through a preliminary stage, up to the final detailed decommissioning plan), and to use the locally adapted, calculation specific data. This approach to decommissioning costing is known as the ‘bottom–up principle’ and is considered to be the most accurate [1].

Another example of how to overcome the discrepancies in decommissioning costing is the application of the ISDC [4] as the cost calculation structure that generates the cost directly in a standardized format or, at least, converts the cost data calculated in a non-standardized structure into the ISDC format. Experience shows that application of this standardized structure is very efficient in comparing the decommissioning costs of various nuclear power plants, even when comparing the cost developed using different costing approaches. An example of this can be found in the IAEA cost benchmarking study for nuclear power plants of the WWER-440 type [13].

6.2. COST ESTIMATING

Currently, there is no universally accepted standard for developing decommissioning cost estimates, or for that matter, any clear reference for the terminology used [1]. Some generalized approaches can be found in Refs [1, 14]. The level of detail of cost estimates and costing approaches may differ, starting from the preliminary costing stages up to final costing. A review of these aspects is given in Ref. [1].

6.2.1. Types of cost estimate

There are three types of cost estimate that can be used, and each have a different level of accuracy [1]:

(i) Order of magnitude estimate: One without detailed engineering data, where an estimate is prepared using scale-up or -down factors and approximate ratios. It is likely that the overall scope of the project has not been well defined. The level of accuracy expected is −30% to +50%.

(ii) Budgetary estimate: One based on the use of flowsheets, layouts and equipment details, where the scope has been defined, but the detailed engineering has not been performed. The level of accuracy expected is −15% to +30%.

(iii) Definitive estimate: One where the details of the project have been prepared and its scope and depth are well defined. Engineering data would include plot plans and elevations, piping and instrumentation diagrams, one-line electrical diagrams and structural drawings. The level of accuracy expected is −5% to +15%.

It is apparent from these estimate types and the levels of accuracy expected that even in the most accurate case, a definitive estimate is only accurate to −5% to +15%. The cost estimator needs to exercise judgement as to the level that the input data will support. In developing a funding basis for a project, the estimator includes sufficient margin (or contingency) to account for a potential budget overrun to account for this level of accuracy.

6.2.2. Approaches in cost estimating

Costs may be estimated in a number of ways. Recorded experience from other decommissioning projects, estimating handbooks and equipment catalogue performance data are some of the sources used to develop cost data. The techniques used for preparing cost estimates will necessarily vary with the project’s degree of definition; the state of the art of the project; the availability of databases, cost estimating techniques, time and cost estimators; and the level of engineering data available. Some of the more common estimating techniques are [1]:

- Bottom-up technique: Generally, a work statement and set of drawings or specifications are used to extract material quantities required for executing each discrete task performed in accomplishing a given activity. From these quantities, direct labour, equipment and overhead costs can be derived.
- Specific analogy technique: Specific analogies depend upon the known cost of an item used in prior estimates as the basis for the cost of a similar item in a new estimate. Adjustments are made to known costs to account for differences in relative complexities of performance, design and operational characteristics.

— Parametric technique: Parametric estimating requires historical databases on similar systems or subsystems. Statistical analysis is performed on the data to find correlations between cost drivers and other system parameters, such as design or performance. The analysis produces cost equations or cost estimating relationships that may be used individually or grouped into more complex models.
— Cost review and update technique: An estimate may be constructed by examining previous estimates of the same or similar projects for internal logic, completeness of scope, assumptions and estimating methodology.
— Expert opinion technique: This may be used when other techniques or data are not available. Several specialists may be consulted iteratively until a consensus cost estimate is established.

The method widely adopted in estimating is the bottom-up technique, based on the approach known as the work breakdown structure (WBS). Using this approach, a decommissioning project is divided into discrete and measurable work activities. This division provides a sufficient level of detail so that the estimate for a discrete activity can apply to all occurrences of the activity. Measurable work activities are generalized as unit factors that represent the calculated quantities (workforce, costs, consumables, etc.) related to normalized quantity of input variable (mass, surface, length, etc.). These two approaches, the bottom-up technique and the unit factor approach, are the basis of costing methodologies.

6.3. COSTING PROCEDURES

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 activity, which is subdivided into a series of discrete and measurable elementary work activities for which unit costs are calculated or estimated (unit cost factor approach).

Examples of elementary repetitive activities are the cutting of a unit length of pipe or removing a valve, a pump or a unit quantity of concrete, etc. 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 required in order to assess workforce requirements, work efficiencies and time schedules.

6.3.1. Steps in decommissioning costing

The main steps in decommissioning costing, as identified in existing costing approaches, are as follows.

6.3.1.1. Definition of cost elements

Definition of cost elements includes identification of the typical cost categories, noting applicable calculation methods. Costs are classified into the categories, depending on the nature of decommissioning activities, the methods of cost calculation and the types of main input variable. Typical categories of costs are activity dependent costs, period dependent costs, collateral costs, costs for special items and contingency. The procedures implemented in the costing methodologies are also similar in principle for the individual cost categories. The differences can be identified in the level of detail and in the structure of the cost items.

6.3.1.2. Identification of hands-on activities

In the unit cost factor approach, the decommissioning plan should be developed in terms of discrete basic activities for which unit costs are defined. The list of activities must be completed with a plant building and equipment inventory in order to define the extent of each activity. As an example, such an inventory should include all elements of systems and structures such as pipes, valves, components of reactors, building surfaces, elements of civil structures, etc. The inventory items should be characterized by parameters relevant to decommissioning, such as identification data in relation to the facility, decommissioning category, mass, surfaces, material type and radiological parameters and other data that are required for calculation of decommissioning parameters (costs, workforce, etc.) and data for waste management.

Interaction of the list of decommissioning activities with the facility inventories gives the required extent of the cost calculation structure. In this way, the typical decommissioning activities related to systems and structures, such as 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 facility inventory database developed prior to development of the calculation structure. In simple or preliminary costing methodologies, a manual approach for developing the calculation structure is used. In the detailed costing stages, an automatic generation of the calculation structures may be used based on the list of decommissioning activities and the inventory database and using conditions defined for the automatic generation of the calculation structure.

6.3.1.3. Definition of unit factors

Unit cost factors, as the quantities measured against normalized input variables, are defined in accordance with the detail of the items considered in the plant inventory and with the listing of decommissioning activities for a decommissioning project. As an example, unit cost factors may be defined for cutting of a normalized mass of pipe of a certain size (a ‘decommissioning category’). This approach consists of developing the basic unit factors for costs, workforce, consumables, etc., for ideal conditions. An example is the cutting of a non-contaminated pipe at a worker’s waist height (0.5 m from the dismantled equipment) without any risk of radiation exposure.

Basic unit factors incorporate the requirement for labour hours per unit activity (under ideal conditions) and the local expenses related to labour per work hour, taking into account the different worker and craft categories. Additionally, various coefficients or correction factors may be considered that reflect specific working conditions, e.g. working at height, the need for protective equipment (respirators, protective clothing), accessibility of the working area, dose rate levels (implementation of ALARA measures), work breaks and other productivity losses. The coefficients are known as work difficulty factors (or ‘increase’ factors). In addition, the final value of a unit factor may be corrected to include material and equipment costs whenever these are directly proportional to the extent of work.

Unit factors for waste management may be defined, for example, per unit volume, mass, containers, etc., for the waste of each type.

6.3.1.4. Definition of period dependent activities

On the basis of the plant inventory and unit factor approach, the duration of individual work phases involving the hands-on activities in a decommissioning project may be calculated. The relation and linkage 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 startup or continuation of all other remaining 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 the duration of period dependent decommissioning activities.

An additional estimate is required to define the size of the staff involved in management, administration and other supporting activities, which are typical period dependent activities. The relation between period dependent activities and activity dependent decommissioning activities is the subject of optimization. The project duration may be shortened by increasing the size of the crew for activities on the critical path (number of working groups, number of working shifts).

Moreover, if major parts of the decommissioning activities are subdivided into well defined work packages that may be implemented by subcontractors, the owner’s staff requirements may be reduced during these decommissioning stages.

When defining the staff for period dependent activities for costing purposes, the qualifications of personnel should be considered. The labour cost for different qualification stages may differ significantly, and may also be the subject of optimization.

6.3.1.5. Collateral costs and costs for special items

Some costs may be independent of both the level of activities and the duration of the project. For this reason, they are considered as a separate cost category, i.e. collateral costs and costs of special items, such as the costs of heavy equipment for site support, small tools, nuclear liabilities insurance, etc. Although at least a part of the energy requirement is proportional to the duration of some project phases, energy costs such as costs of lighting, heating or cooling may also be included in this cost category.

The input data required for calculation of these costs is mainly the amount of equipment to be procured for various purposes; lists of periodic payments such as tax, insurance, selected periodic services; lists of periodic payments made during the year (as per the accounting period) for technical media, maintenance, surveillance, permanent services, etc.; and lists of specific non-periodic payments such as permits, licences, external services, consultancies, etc.

Specific items with this cost category are 'negative costs', e.g. the incomes from the sale of scrap or reusable equipment. Care should be taken when evaluating the income from scrap and reusable equipment, as it is unlikely that the surplus material or equipment may be sold at the full cost per unit of the material. The practical extent of sale should be considered.

Another factor to be considered for this type of cost is the identification of the 'time points', i.e. when the individual cost items should be considered. In the case of periodic and permanent payments, they may be incurred each year of the decommissioning project; in the case of procurement of equipment and non-periodic payments, the time points are derived from the decommissioning schedule.

6.3.1.6. Total costs and contingency

The total cost estimate is obtained as a sum of the costs estimated in the three cost categories. In general, the activity dependent costs are calculated on the basis of activity lists, plant inventories and unit cost factors; waste management costs are calculated on the basis of 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. Before summing up, the cost estimates are adjusted to include a contingency that reflects the level of uncertainty in the estimates.

Contingency can be applied as a general contingency equal for all calculation items (normally as a percentage of calculated values) or as an individual value specific for individual elementary calculation items (as a percentage of the calculated value). As an alternative, or sometimes in addition, a general contingency may be applied to the total cost estimate; this approach is used in very preliminary cost estimates, where not all cost drivers are identified.

Allocation of a reasonable level of contingency to individual calculation items or groups of calculation items is a key step in decommissioning costing. The experience gained from actual decommissioning projects should be considered, and also the estimation of unforeseeable items specific for the given decommissioning project should be taken into account. As a result, the contingency may vary from 15% for the removal of non-contaminated equipment outside of the controlled area to 75% for dismantling of reactors [15].

Contingency is applied in a 'graded' approach. In the preliminary stages of cost estimation, the averaged allocated contingency may be at a level of up to 30%. During the periodic re-evaluation, and due to the higher accuracy of data used in cost estimation, the level of contingency is gradually decreased. At the level of the final decommissioning plan, the average contingency may be at the level of 5–10% [15].

6.3.2. Structure of calculated costs

Costs and other project management data (workforce, dose to workers, volumes of waste, etc.) estimated for a decommissioning project may be structured into various formats for presenting calculated data for a decommissioning project, such as:

(a) Total values of the project management data for the project;
(b) Values of project management data relevant for the tasks of the decommissioning schedule;

(c) Cost data formatted according to the structure of decommissioning activities specific for the decommissioning project;
(d) Cost distributed on a yearly scale for the whole duration of the project.

Data (a) are the basic data for presenting the main parameters of the project. Data (b) are the data used for management of the project. Data (c) are used for presenting the project cost structure according to the project specific structure of activities or in a format prescribed by national legislative, financial or other requirements. Sometimes, this structure of decommissioning activities is named the project cost structure; this gives rise to differences or discrepancies between comparisons of individual decommissioning projects.

Data (d) are used for management of the decommissioning fund: for collecting the fund and for financing of the decommissioning activities of the project. The cost data formatted on a yearly scale are also the subject of adjustment for the inflation and discount rates and generally for evaluating the optimum concept for collection and management of the funds, i.e. the decommissioning fund ‘provisioning’.

Implementation of the ISDC into the decommissioning costing gives at least two approaches in the formatting of calculated costs:

(i) The calculated costs have the prescribed fine structure of cost groups for each calculation item: the total cost and its distribution as labour cost, investment, expenses and contingency;
(ii) For decommissioning activities, the calculated costs are formatted according to the ISDC structure, i.e. according to the harmonized structure of decommissioning activities.

Implementation of the ISDC entails formatting the cost in a matrix structure; the cost groups are presented in the horizontal direction (also, other decommissioning parameters such as workforce, exposure, quantity of waste, etc.) and in the vertical direction, the decommissioning activities are ordered according to the ISDC work breakdown numeric identifiers. This enables additional possibilities for processing the costs, such as developing a risk assessment.

6.4. PRACTICAL ASPECTS OF DECOMMISSIONING COSTING

Decommissioning costing represents a set of manifold activities that involve the following principal steps for practical implementation.

6.4.1. Preparation of the inventory database

The inventory database has three main components: (i) the inventory of systems, (ii) the inventory of structures and (iii) radiological parameters. The systems and structures inventories normally refer to identification of the inventory item in the building structure — floor, room and equipment structure — and to parameters such as mass, surfaces, volumes, categories of systems and structures, and materials. The radiological parameters refer to contamination of inner and outer surfaces, activation of construction materials and dose rates (all of them resolved by radionuclide content).

Inventory items are introduced by performing a direct inventory in the individual rooms, based on both an analysis of the documentation and on an inspection on-site. The radiological parameters are measured directly on-site or are calculated based on models of plant and equipment. Special care has to be taken for the calculation of the activation of reactor construction materials.

6.4.2. Preparation of the database of unit factors

Items of this database are unit factors for performing the individual decommissioning activities such as workforce unit factors, secondary waste production unit factors, consumable unit factors (electricity, gas, water, etc.), working group composition and its parameters (skills, labour unit cost factors, exposure parameters, etc.), structure of the working time, parameters of equipment for waste processing, radionuclide parameters, parameters for material and radioactivity flow control modelling, constants, correction factors, various technical or economical parameters, etc.

6.4.3. Generation of calculation options

Calculation options, developed for the nuclear facility to be decommissioned, are based on existing or planned decommissioning infrastructure and the selected decommissioning strategy. The extent of calculation options should cover all relevant possibilities being considered: immediate or deferred decommissioning options and their respective end states, combined with various scenarios for waste treatment. The calculation options are then created based on the decommissioning inventory database and extent of decommissioning activities intended within the scope of the calculation option.

The generation of calculation options can be manual, or some advanced computer codes enable automatic generation of the calculation option based on the inventory database and template calculation structures. The default calculation data are automatically corrected based on the inventory data. The generated options are subsequently checked and adjusted to a final calculation structure by defining the extent of the calculations and inputting or modifying the calculation values.

6.4.4. Calculation and optimization of options and selection of the optimum option

Each decommissioning option is calculated individually, and the calculated data are formatted into output files. Optimization of options is also performed individually using the optimization means available. Optimization represents adjusting the time structure of the option and relevant optimization parameters, e.g. the number of working groups and number of shifts for performing critical activities and adjusting the duration of time dependent activities. Optimization is, in general, an iterative process. Each iteration step includes the adjustment of parameters, the timing of the schedule, durations and recalculation/re-evaluation of the calculated parameters. The result of this phase of costing is a set of optimized decommissioning calculation options for the nuclear facility.

Finally, the optimum calculation option is selected from the set of calculated and optimized options for the nuclear facility. The recommended procedure for choice may be performed by multiattribute analysis [9]. The input data for multiattribute analysis are calculated data for each option entering the analysis, completed with the addition of subjective data delivered by the evaluators. The option with the best characteristics is then taken as the most favourable option for decommissioning of the given nuclear facility. The selected decommissioning option is then processed to the final level of detail required for detailed planning and managing of the decommissioning activities.

6.4.5. Grading in decommissioning costing

In practice, the largest impact on decommissioning costs is likely to be the strategic decisions taken on the overall objectives for a particular facility and any programme of phasing of the work. Reliable estimates are required to make those strategic decisions, and will be required for the work that is decided upon. Dismantling tasks in decommissioning may be viewed as the equivalent of construction in reverse. Complications appear in the management of uncertainties and in dealing with a number of technical unknowns frequently occurring in decommissioning projects. Using estimation techniques from construction projects only gives part of the answer. All relatively straightforward known aspects of the project should be handled in as structured and objective a way as possible. Decommissioning cost estimates may then be made using established project management techniques, in particular, the project should be treated in a fully structured way, including a WBS.

The basic elements for a relevant cost evaluation methodology are the availability of a well developed decommissioning plan, a detailed material analysis, an evaluation of the required working steps and a proposed time schedule. Different quality estimates would normally be derived for decommissioning projects, perhaps in three stages [14]:

(i) Option studies, which may comprise part of the strategic decision making process and which may be carried out with as wide a range of options as can be managed. Cost estimates based largely on experience are provided, showing a relatively low order of accuracy (order of 50%).

(ii) An engineering concept, when a choice between options is to be made and initial approval of safety and financing for the project is to be obtained, requiring an estimate at a better level of accuracy (at a level of 30%).
(iii) A detailed engineering evaluation, based on the project structure and built ‘bottom’ upwards from the lowest level, in order to give the overall cost of the project, up to the highest level of accuracy, perhaps approaching 10%, before proceeding to the final approval of the whole project.

Management of unknowns remains a major feature of all decommissioning work. At the estimate stage, it is appropriate to include provisions for two groups of uncertainties. A contingency on costs should be provided, as costs may not turn out to be as the estimator imagined, which is a relatively familiar concept in construction work. In addition, programmes may be interrupted, perhaps for reasons of difficulties with regulators, and programmes may be extended, requiring an estimate for managing the time contingencies in a programme.

7. IDENTIFICATION OF DECOMMISSIONING ACTIVITIES FOR COSTING

The principle of estimating the decommissioning cost as implemented in this publication, and based on the evaluation of decommissioning activities, is called ‘activity based costing’. One of the most important issues of this approach is the proper identification of all activities involved in a 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 a facility specific file and in relation to the structure of the hands-on activities.

This section describes decommissioning activities in general and also presents specific features of decommissioning activities for research reactors. Activities of a decommissioning project are normally presented in the decommissioning plan 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 conditions.

In decommissioning costing, as one of the main inputs for calculation and optimization of decommissioning parameters, a set of decommissioning activities is developed as the decommissioning WBS and presented in the decommissioning plan. A recommended structure for a decommissioning plan is given in Ref. [10], which also presents procedures for selecting decommissioning activities.

However, in the case of preliminary costing stages, the decommissioning plans may not be available. In these cases, the role of the decommissioning plan may be replaced by the ISDC, which represents a comprehensive list of typical decommissioning activities. Instead of using the decommissioning plan as the source for identification of relevant decommissioning activities for a decommissioning project, the ISDC may be used as the checklist for this purpose.

7.1. TYPICAL DECOMMISSIONING ACTIVITIES FOR RESEARCH REACTORS

The term ‘decommissioning’ is defined as the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a nuclear facility after its shutdown and the return of its site to a planned end state accepted by the national legislation. In order to achieve this state, actions and activities have to be undertaken, such as decontamination, dismantling and removal of radioactive material, waste, components and demolition of the facility structures, as well as management of the waste and radioactive waste arisings. The actions are carried out to achieve a progressive and systematic reduction in radiological hazards on the basis of preplanning and required approval of the plans for these activities in order to ensure public and occupational safety during and after decommissioning operations and protection of the environment.

A specific feature of these activities is that they have to be thoroughly planned. The plans have to be approved not only by the licence holder, but also by the appropriate authorities before their implementation, which has to be carried out by trained and qualified personnel.

The extent of decommissioning activities depends on the strategy of decommissioning selected, which also includes the definition of the end state. A wide variety of strategies and end states is identified in the decommissioning of research reactors [6, 10]. Strategies may be immediate or deferred dismantling, and also, in the case of research reactors, entombment strategies may be considered. This implies the fact that the structure of decommissioning activities may be manifold.

Typical decommissioning activities and a procedure for decommissioning a research reactor with the implementation of the immediate dismantling strategy are presented in Ref. [6]:

(1) Compile the 'as-built' drawings and verify that they reflect the current status of the reactor and associated plant.
(2) Define the safety and environmental principles.
(3) Through characterization, prepare the inventory of radiological and toxic materials in the plant.
(4) Establish the waste management procedures.
(5) Assess the alternative decommissioning options.
(6) Justify the proposed option.
(7) Define the equipment and staff requirements.
(8) Perform safety and environmental assessments.
(9) Prepare cost estimates, determine the source of funds and obtain approval.
(10) Prepare the decommissioning plan from the above data.
(11) Prepare detailed work packages, including the required resources.
(12) Submit the plan and the decommissioning licence request to the regulatory body, where appropriate.
(13) Obtain regulatory approval of the plan, where appropriate.
(14) Implement the approved decommissioning plan.
(15) Complete dismantling.
(16) Obtain approval of the final radiological survey plan from the regulatory body, if required.
(17) Complete the final site cleanup and radiological survey.
(18) Obtain approval from the regulatory body for the licensee to be released from responsibility for the site.

Typical decommissioning activities performed during the decommissioning of research reactors, are as follows:

— Preparing for decommissioning includes spent fuel management, where specific solutions should be developed. This is in contrast to power reactors, where the fuel cycle is normally well established.
— Preparing a radiological characterization that represents an extensive activity prior to planning of decommissioning and planning activities, which include developing the documentation for licensing of decommissioning.
— Decontamination and dismantling activities such as predismantling decontamination, dismantling of contaminated systems (manual and remote segmentation techniques), dismantling of embedded elements (a specific feature of research reactors), dismantling of activated and contaminated structures of the reactor and biological shield, dismantling of auxiliary systems, decontamination of building surfaces and final radiological monitoring of structures before their release.
— Waste management activities that, in many cases, have special features in comparison with the decommissioning projects for power reactors where enough money should be available for establishing the full extent of waste management. The waste management scenarios for research reactors can have specific features resulting from limited possibilities in selecting the waste management technologies.
— Site restoration and release, which include the management of contaminated areas, dismantling of non-contaminated systems outside the controlled zone, demolition of structures, site restoration, final survey and site release activities.
— Other decommissioning activities, such as management, support activities, activities for ensuring safety, surveillance and maintenance, research and development and others.

Additional care and maintenance activities should be identified for the storage periods if a deferred dismantling option is selected.

All the decommissioning activities listed above are represented in the ISDC. In the costing model for research reactors (Section 10), the ISDC is used for identification of decommissioning activities for the purpose of developing the decommissioning costing.

7.2. THE ISDC

The reason for issuing the original standardized cost structure [1] was the inconsistencies in presented costs for various decommissioning projects caused by the different extents of activities, technical, local and financial factors, waste management systems, etc. [2]. The main purpose of the original publication [1] and the upgraded ISDC [4] is:

- To facilitate communication;
- To promote uniformity;
- To encourage common usage;
- To avoid inconsistency or contradiction in the results of cost evaluations;
- To be of worldwide interest to all decommissioners.

One of the objectives of the IAEA in decommissioning costing is the promotion of harmonization in presenting decommissioning costs [1]. Ideally, the cost should be presented in ISDC format [3]. Other than presenting costs in ISDC format, the next logical step is the harmonization of decommissioning costing. There are two principal methods for implementation of the ISDC structure:

(i) Use of the ISDC structure for the mapping of cost data from costing structures based on a WBS;
(ii) Use of the ISDC as the cost calculation structure.

On the basis of current experience and definitions, costing is the process that considers individual elementary activities (bottom-up principle) and is generally organized according to two structures: the WBS of a decommissioning project and/or the ISDC structure in an extended form as the cost calculation structure. In principle, the cost calculating methodologies are the same, but they may differ in some detail as to the extent of calculated data and in the sequence of the calculation steps.

A WBS organizes the elementary decommissioning activities according to the planned structure and sequence of work packages. The work packages are organized in a hierarchical structure, which is normally transformed on to a Gantt chart, to which project planning and management methods may be applied. This is the standard approach for the identification and organization of project activities. The detailed structures of a WBS are specific for individual projects. However, some generalities may be identified for projects on similar types of nuclear facility.

7.3. METHODS FOR DEFINITION OF DECOMMISSIONING ACTIVITIES FOR COSTING

The principle of the bottom-up approach means that decommissioning activities should be identified at the lowest level of detail in order to develop a definitive cost calculation structure for the project. The procedure for identification of decommissioning activities is different for individual cost categories, and grading can be implemented in defining the decommissioning activities:

(1) *Hands-on activities.* The level of detail should be adjusted to the level of detail in the inventory database. The extent and types of decommissioning activity for costing can differ significantly from preliminary studies up to the detailed costing. The methods for identification of activities for hands-on activities are presented below in this section. Special cases are the activities for waste management.

(2) *Period dependent activities and collateral costs.* The level of detail of decommissioning activities is proportional to the details of the decommissioning project. The activities may be defined at the second or third ISDC numbered level in preliminary costing cases. In detailed costing structures, the activities are defined at the lowest level, i.e. the calculation level. The WBS of the project determines the depth of the lowest calculation levels. The phasing of decommissioning projects plays an important role in the definition of period dependent activities and collateral costs due to repetition of the same activities under different conditions in individual phases.

7.3.1. Decommissioning activities related to inventory

The approach 'fixed on top, open downwards' as used in implementation of the ISDC for the cost calculation structures enables definition of various cost calculation structures as follows [6]:

— An inventory oriented approach, when the calculation procedure is organized according to the content of the inventory database;
— A room oriented approach, when the dismantling and other typical activities, such as decontamination of building surfaces, radiation monitoring, etc., is organized room by room, and the same sets of preparatory activities prior to dismantling (or other activities) and finishing activities are repeated for each room;
— A system oriented approach for organizing the decommissioning activities is applied mostly for the equipment with large dimensions and complex structures such as reactors, refuelling machines, steam generators and other large components of the primary circuit.

The inventory oriented approach is implemented mostly for preliminary costing stages and, to some extent, also for conceptual costing stages. The inventory of the facility in these cases is identified by a limited number of inventory items, typically several tens to several hundreds of items for systems, surfaces and structures.

The room oriented structure of dismantling activities is the basic approach used for dismantling equipment that is located in small and medium sized rooms (not large rooms such as the reactor hall). The equipment within these rooms is mostly in standard decommissioning categories, such as pipes, valves, etc., for which standard unit factors can be used (i.e. not complex equipment). A room based approach means the repetitive implementation of a set of preparatory activities before dismantling, a set of dismantling activities according to the inventory of components to be dismantled within the room and a set of finishing activities after dismantling within the room. Similar sequences of elementary decommissioning activities may also be defined for other activities related to rooms, such as the decontamination or monitoring of building surfaces. The principle is represented in Fig. 1.

Procedures for the system oriented approach are specific for each component, and normally, dismantling is the reverse procedure to construction. The structure of decommissioning activities is specific to the system being dismantled and is typically organized according to the individual construction of the subassemblies of the dismantled system. This procedure is facilitated by the fact that the technical documentation for complex systems, such as construction, materials, recommended procedures for maintenance, etc., is organized by subassemblies.

The approach to system oriented dismantling is represented in Fig. 2. The set of preparatory, dismantling and finishing activities is repeated in the calculation structure for each construction subassembly. The set of preparatory and finishing activities may be similar to the room oriented approach; relevant activities for calculation are selected when defining their scope. Additional specific activities may be defined further. In comparison with the room oriented approach, additional sets of activities are defined at the beginning and the end of the dismantling sequence for general preparatory and finishing activities and a set of continuous supporting activities: radiological monitoring, waste removal, maintenance of dismantling equipment, etc.

Selection of these additional preparatory, finishing and supporting activities depends on the constructional complexity of the system to be dismantled and on the dismantling system used. These specific activities are defined case by case as period dependent activities for which the duration, the personnel and radiological conditions are defined.

Set of preparatory activities:

- Covering the floor with protective foils
- Installation of scaffolding
- Installation of temporary supply systems
- Installation of temporary ventilation system
- Radiation survey in the room
- Marking of cutting lines and surfaces
- Transport of dismantling tools into the room
- Preparation of dismantling tools in the room
- Disconnecting/checking of equipment to be dismantled
- Installation of the protective tent
- Preparation of the workgroup for dismantling
- Preparation of waste transport containers
- Specific additional preparatory activities

Set of dismantling activities according to the ALARA principle:

- Dismantling the inventory item with the highest dose rate
- Sequential dismantling of inventory items according to decreasing dose rate
- Dismantling of the last inventory item with the lowest dose rate

Set of finishing activities:

- Removal of dismantling tools from the room
- Removal of the protective tent
- Removal of the scaffolding
- Removal of protective foils from the floor
- Removal of the temporary connection to electricity
- Removal of the temporary ventilation
- Removal of waste transport containers
- Clean up the room (industrial vacuum cleaning)
- Specific additional finishing activities

FIG. 1. Principle of room oriented approach for hands-on decommissioning activities. ALARA: as low as reasonably achievable.

A similar scheme for the structure of decommissioning activities can also be applied in the case of one piece removal. The structure of decommissioning activities involves a set of specific activities relevant for the one piece removal scenario, starting from specific preparatory activities, case specific dismantling activities, transport to the end position of the one piece removal and, at the end, the specific set of finishing activities. The sequence of activities is supported by a set of supporting activities.

Grading can be implemented effectively in defining the decommissioning activities for decommissioning costing. As an example, if the inventory database is developed for preliminary cost studies as a list of some tens to hundreds of items, summarizing the list of decommissioning activities may be simple, e.g. only considering dismantling activities based on a short list of inventory items and adding relevant contingency for preparatory and finishing activities.

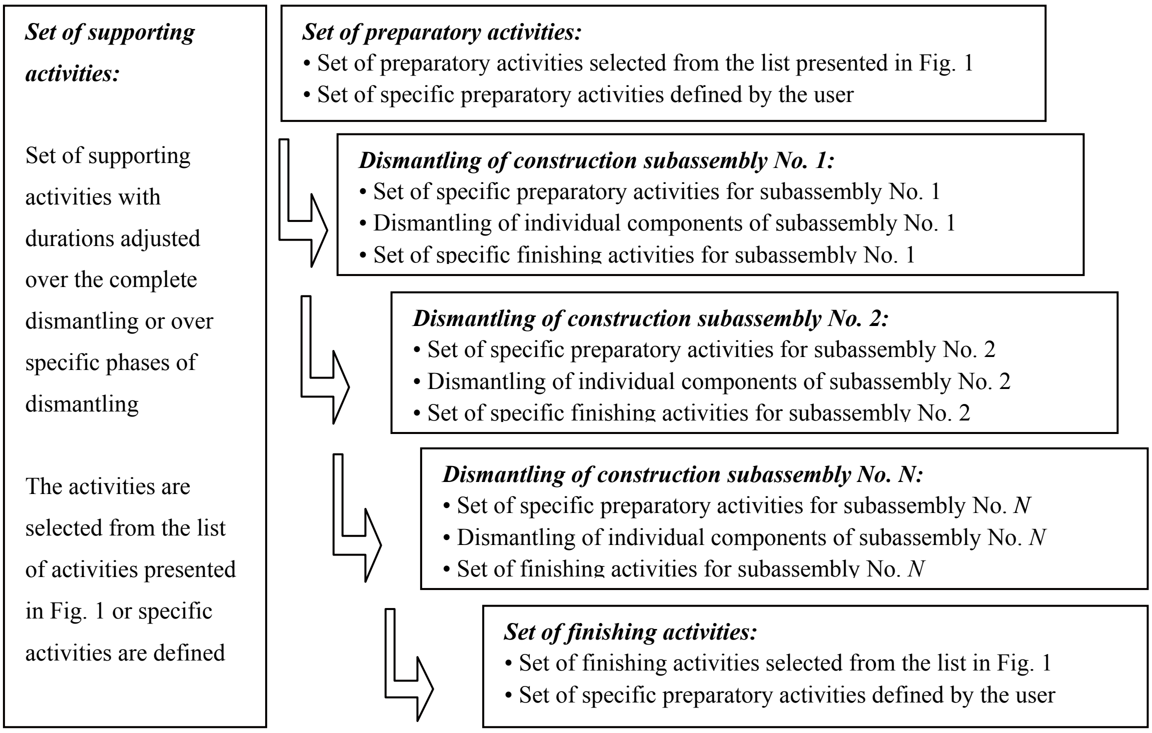

FIG. 2. Principle of system oriented approach for hands-on decommissioning activities.

7.3.2. Waste management activities

Waste management activities within a decommissioning project should ensure the processing of the following types of radioactive and non-radioactive waste:

— Historical/legacy waste of any type accumulated and stored at the facility to be decommissioned, including the retrieval of waste from storage;
— Operational waste of any type accumulated at the facility until shutdown;
— Radioactive and hazardous decommissioning waste of any type from decontamination and dismantling activities;
— Conventional and hazardous waste from conventional dismantling and demolition.

Processing of waste includes all partial waste retrieval, pretreatment, treatment, conditioning and disposal techniques. The final end state for any type of waste items may be:

— Disposal of radioactive waste in disposal facilities of various types (such as deep geological repositories, near surface repositories, landfills);
— Conditional or unconditional free release of reusable materials that fulfil the conditions for release;
— Disposal of hazardous waste at dedicated repositories;
— Reuse of conventional materials;
— Disposal of conventional waste at standard waste dumps.

The costing of processes for waste management is also based on the principles of 'activity based costing'. This means that individual waste management processes should be identified for which the cost categories can be defined, i.e. activity dependent, period dependent and collateral costs. Most of the waste management processes are of the activity dependent type, i.e. the volume of work is dependent on the quantity of waste to be processed. Period dependent activities in waste management are support, management, surveillance, radiation protection and other similar activities. Collateral costs are mostly the activities for procurement of equipment, materials, consumables and payments. In any decommissioning project, a waste management system should be established. An example of a decommissioning waste management system is given in Fig. 3.

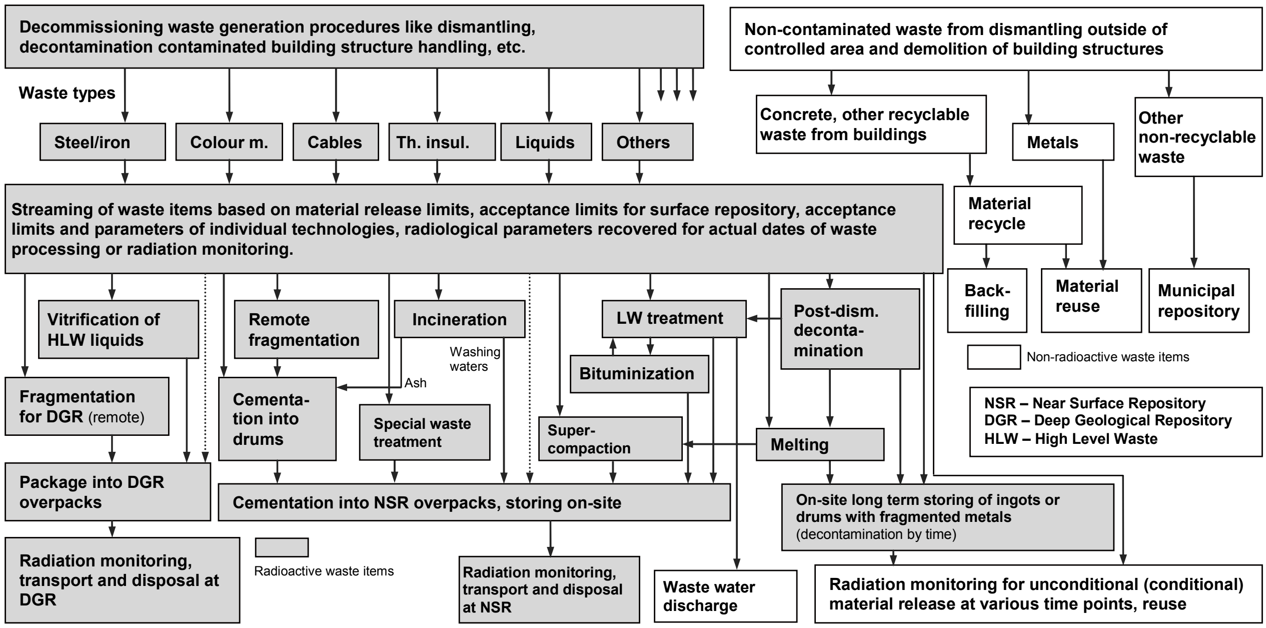

FIG. 3. Example of a decommissioning waste management system.

The system is the basis for the identification of elementary decommissioning activities. The decommissioning waste management system is broken down into individual elementary waste processing activities that are then the subject of costing. Some of the activities of the decommissioning waste management system may be operated within the decommissioning project; some are contracted out as services. An example of part of a decommissioning waste management system is given in Fig. 4, which presents an example for processing of radioactive metals from decommissioning. Individual activities are considered as elementary decommissioning activities for which costs are estimated, based on the capacity of individual techniques, personnel and consumables required for the operations on the quantities of processed waste of a given type. Investment costs are evaluated as procurement or depreciation, as examples.

Using the approach presented above and examples, the waste management system may be developed.

For cost estimating, the following main groups of data are required:

— List of the elementary waste management techniques;
— Unit factors for the elementary waste management techniques;
— Quantities of waste to be processed in the elementary waste management techniques.

There are several IAEA recommendations related to the costing of waste management activities, the two most important relate to use of the IAEA classification of waste [15] and to the use of the ISDC [4]. These aspects are presented and discussed in Section 9 of this publication.

7.3.3. Period dependent activities and collateral costs

Period dependent activities in a decommissioning project are normally the activities related to:

— Preparation and planning for decommissioning;
— Most of the shutdown activities;
— Managing of decommissioning and related activities;

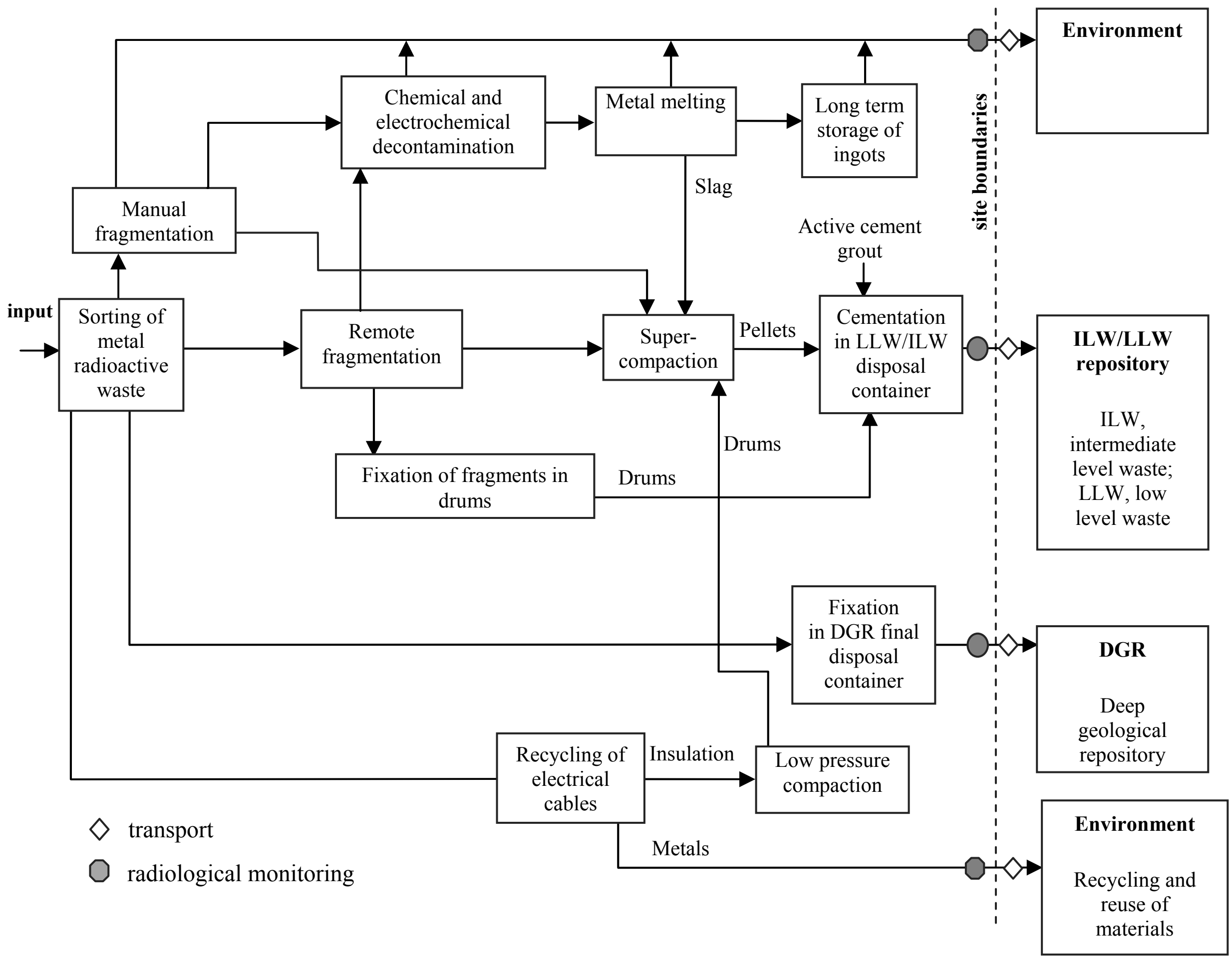

FIG. 4. Example of part of a decommissioning waste management system with identification of elementary waste processing techniques.

— Support activities;
— Activities for radiation and industrial safety;
— Surveillance and security;
— Maintenance;
— Operation of auxiliary systems;
— Research and development;
— Other activities not directly related to inventories.

The basis for identification of period dependent activities is mostly the WBS of a decommissioning project. Data required for cost estimation are the data for personnel involved in these activities and duration, which are estimated individually or derived from the work breakdown schedule. Fixed cost items or period dependent cost items may be estimated as part of these activities. Collateral costs are identified as lists of items for the procurement of equipment, consumables and materials, and as payments of various types, such as tax, insurance, payment to authorities, as examples.

Period dependent activities and collateral costs of the same type may be repeated several times within a decommissioning project due to the phasing of the project. Period dependent activities of the same type should be evaluated separately in individual phases owing to different requirements in the various phases. Figures 5 provides an example of phasing of a decommissioning project with deferred dismantling with identification of phasing of typical decommissioning activities according to the ISDC.

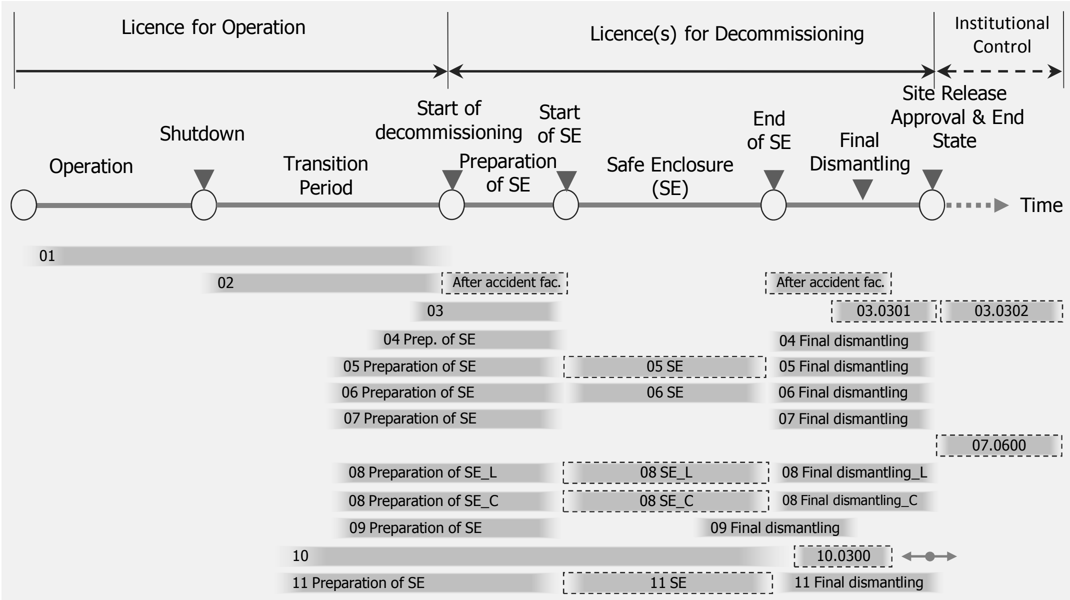

FIG. 5. Example of phasing of the ISDC [4].

8. INPUT DATA FOR DECOMMISSIONING COSTING

This section reviews the main groups of input data used for the calculation of costs and other decommissioning parameters:

— The facility inventory database that characterizes the facility to be decommissioned;
— The database of unit factors that contains the calculation data and parameters which characterize the processes and personnel involved in individual decommissioning activities;
— Item specific data that are specific for individual calculation items (i.e. local calculation data).

The first two groups are the essential data for the calculation of each option within a decommissioning project; the third group includes the data specific for individual calculation items within the individual options of a decommissioning project.

8.1. FACILITY INVENTORY DATABASE

This section reviews the principal structure of the facility inventory database, the structure of data at individual levels in the inventory database and the general procedure for its development.

8.1.1. Structure of the inventory database

The principal structure of the facility inventory database should correspond to the costing approach under application. In principle, the structure presented in Fig. 6 should be implemented for a room oriented approach, to evaluate the cost at the level of individual building objects and in order to be able to identify all relevant decommissioning activities.

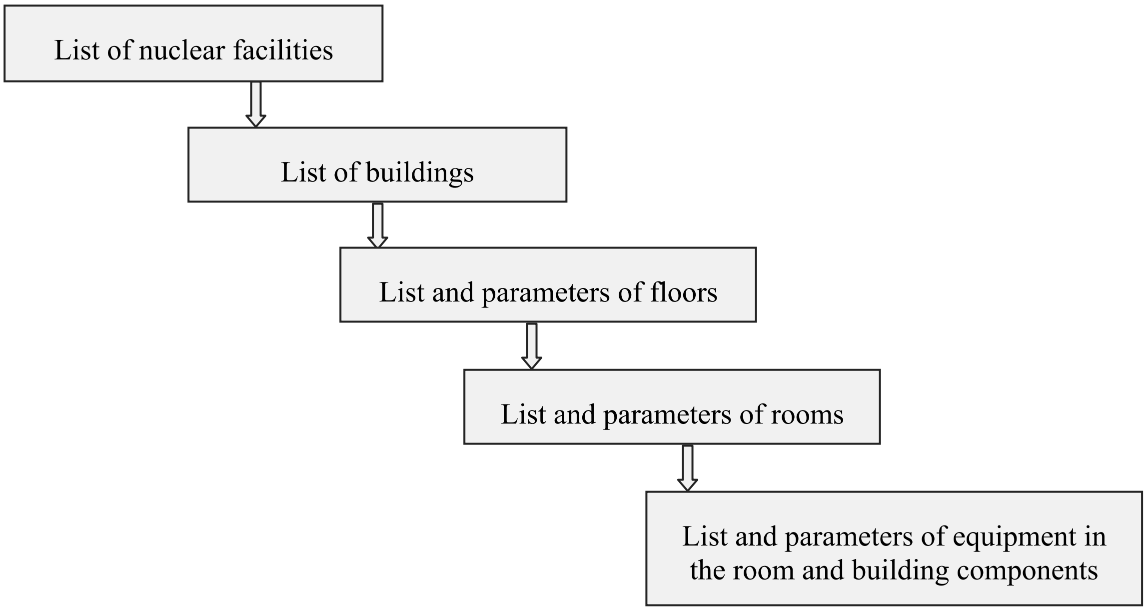

FIG. 6. Principal structure of the facility inventory database for decommissioning costing.

The reasons for the principal structure of the facility inventory database and the requirement for data on individual levels can be summarized as follows:

— In some decommissioning projects, more than one nuclear facility can be the subject of decommissioning. Hence, the inventory data should be identified for individual nuclear facilities.
— The structure of the decommissioning tasks of a project is normally organized according to individual buildings, at least for decontamination and dismantling activities. The data should then be organized according to the buildings.
— The same reasons for the room oriented approach in decommissioning activities are valid for organizing the data by floor level. Some additional specific supporting activities can be organized at the floor level.
— There is a set of decommissioning activities identified at the room level, such as preparatory and finishing activities. Many of them are dependent on the parameters of the rooms, e.g. size. The average dose rate in a room is one of the input data used for calculation of dose to workers.
— The subject of decommissioning activities within a room is the individual items of equipment that represent the elementary decommissioning activities identified for costing. The term equipment means all types of elements within the room for which decommissioning activities can be identified and which are the subject of decommissioning costing. The elements are individual components of systems, embedded elements and various types of surface subject to decontamination and radiation monitoring, together with structures for dismantling.

8.1.2. Structure and content of data

The general structure of data in the inventory database is as follows:

— Identification data, which involve the allocation data for referring to upper levels within the principal hierarchical structure of the facility inventory database, allocation to structures and allocation to systems. Identification data are required for implementation of the room oriented and system oriented dismantling approach.
— Physical data, such as mass, area of surfaces and volumes, which are used as input variables. Physical data can be prepared mainly by the review of technical documentation (project and operational documentation), historical data (operational records), by inspections on-site and by reviewing the experience of operations personnel.

— Radiological data include dose rates, contamination of internal and external surfaces, activation of components of reactors and of the biological shield, mass activity and relevant composition of radionuclides. A comprehensive review for preparing radiological data by in situ measurement and computer modelling can be found in Ref. [16].
— Decommissioning data include decommissioning categories of equipment (see Section 9) within the rooms, which are used for the calculation of decommissioning parameters. These data are specific and are normally prepared by decommissioning experts. Specific types of data of this kind are the ISDC allocated data (ISDC numbers), which are used for development of the ISDC cost calculation structure (Section 9).

The list of buildings contains the individual buildings and the allocation data to the nuclear facility. The list of floors contains the floors relevant to the individual building. The data on the level of floors are allocated at the detailed costing level with reference to defining the waste routes.

Data at the individual room level are used for the calculation of parameters when the room oriented approach is implemented and for the calculation of dose to workers. Typical data are the following:

— Identification number of the room;
— Reference to the floor and building;
— Number of the room (abbreviations);
— Name of the room;
— Physical dimensions of the room;
— Allocation to the controlled area;
— Average dose rate inside the room;
— Nuclide vector of the dose rate;
— Reference date for dose rate and nuclide vector.

Data at the equipment level are used for the calculation of parameters for predismantling decontamination; dismantling of primary and secondary circuit items, biological shield and embedded items; and decontamination and final radiological surveys of building surfaces. Typical data are the following:

— Identification number of equipment or building structure, including identification of database item within the database.
— Name of equipment or building structure.
— Number of room to which the equipment or building structure is assigned.
— Weight of equipment or building structure.
— Inner surface area of technological equipment.
— Outer surface area of equipment or building structure.
— Inner surface contamination of equipment.
— Outer surface contamination of equipment or building structure.
— Nuclide vector for inner surface contamination.
— Reference dates for inner contamination and nuclide vector of inner surface contamination.
— Nuclide vector for outer surface contamination.
— Reference dates for outer contamination and nuclide vector of outer surface contamination.
— Dose rate at the working distance at the equipment or building structure (0.5 m from the surface of the equipment or building structure).
— Nuclide vector of the dose rate.
— Reference date for the dose rate and nuclide vector of dose rate.
— Inner volume of equipment, a parameter used for predismantling decontamination (not necessary for all equipment).
— Specific activity of activated materials.
— Nuclide vector resolved by the specific activity of activated materials.
— Reference dates for specific activity and for the nuclide vector of activated materials.

— Category of the equipment or building structure to allow characterization of the type, shape, dimensions and material composition of technological or building equipment. This parameter is used for the assignment of dismantling and demolition procedures by default.

The content and structure of the facility inventory database can be graded depending on the stage of decommissioning costing (Section 9).

8.1.3. Developing the inventory database

Development of an appropriate inventory database is the prerequisite for effective decommissioning costing. The general procedure for development of the inventory database is presented in Fig. 7. The procedure is divided into four steps where the following groups of data are developed:

— Data of type 'A' are the primary data to be collected from facility technical documentation and are based on physical inspection and measurement in individual premises of the facility.
— Data of type 'B' are the secondary data derived from the primary data by calculation by decommissioning experts.
— Data of type 'C' are the data used in the generation of the calculation database and in the generation (or definition) of the decommissioning calculation options.
— Data of type 'D' are the inventory data for complex reactor structures, developed in separate tasks. Preparation of this kind of data requires additional calculations such as neutron flux calculations, calculations of the activation of materials of reactor construction and the development of a hierarchical inventory database structure that corresponds to the proposed dismantling procedure. A similar approach to developing the inventory may also be used for other complex equipment such as steam generators and components of the primary circuit and other equipment (e.g. refuelling machines). These data should be prepared by decommissioning specialists and are generic ones, applicable for nuclear power plants or research reactors, just to highlight the complexity of 'D' data.
— Data of type 'E' are, in general, radiological data, mostly the contamination levels and the nuclide composition of contamination or dose rates. It is expected that the main radiological parameter — the dose rate at a defined distance from the equipment (i.e. 0.5 m) — is collected as primary data by the operating personnel. Contamination data can then be calculated, based on calculation models of categories of equipment, if they are not available directly as primary data. The nuclide composition can be derived from radiological analysis of relevant samples.

8.2. UNIT FACTORS AND OTHER INPUT CALCULATION DATA

Individual decommissioning activities in a costing model are described by mathematical calculation procedures that, except for facility inventory data, require a set of common calculation data with a broad spectrum of parameters. Parameters describing features of an activity, such as the capacity of a decommissioning technology or technique, consumables and materials used, working group composition (number of workers and their roles), cost parameters (salaries of workers, cost unit factors of consumables and materials), are examples. This section describes the input calculation data required for calculation of the decommissioning parameters in combination with the facility inventory data.

The database contains unit factors and other calculation data such as specific parameters and constants. These data are the second main source of input data for decommissioning costing. They contain the input data specific for the decommissioning project that are normally used as the general data for the project. These data describe the activities that are carried out during the decommissioning process. The database of unit factors can be divided into the following main groups according to the nature of the data:

— General calculation data, including unit cost factors, personnel specific data and other overall data not dependent on specific decommissioning activities;

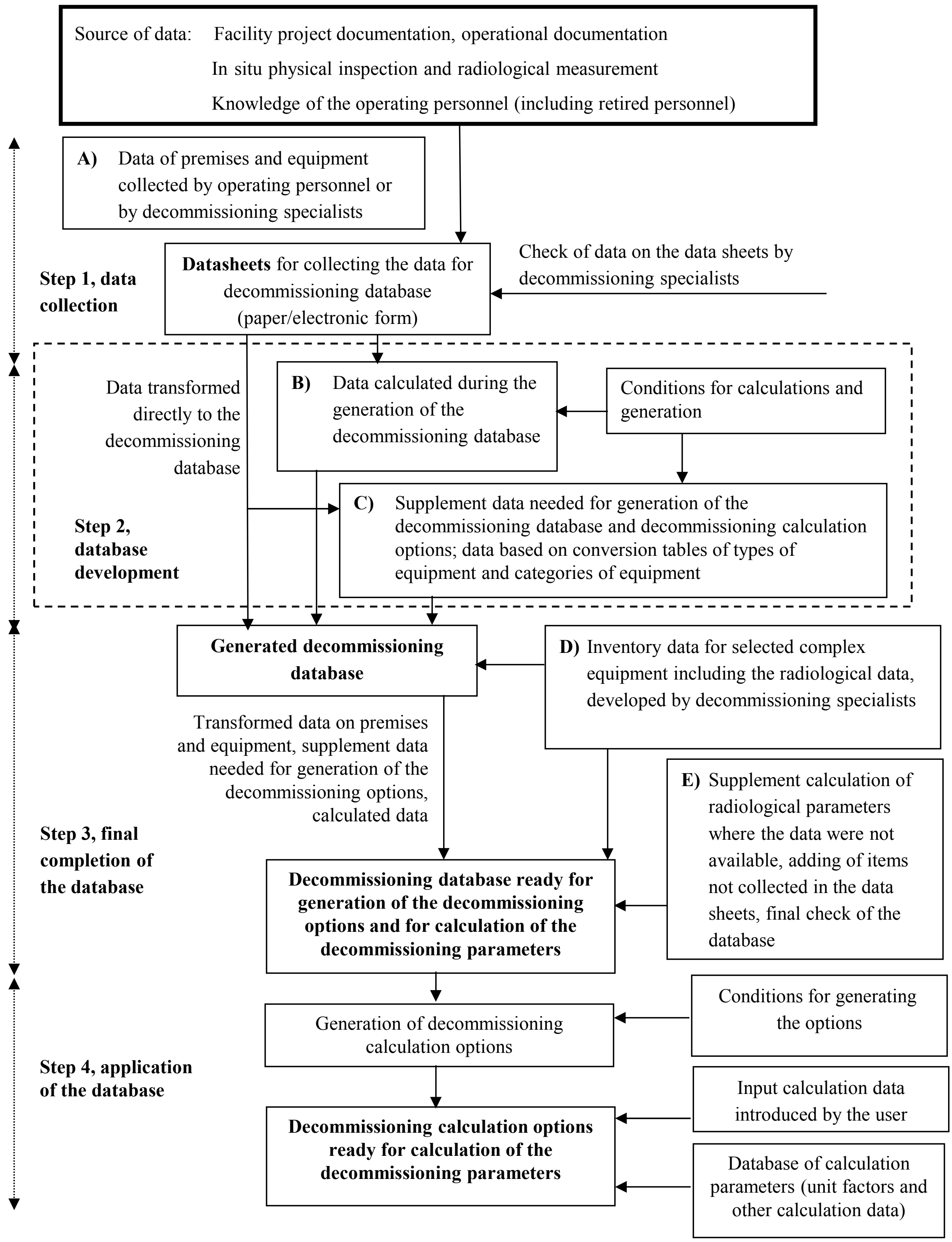

FIG. 7. Review scheme for development of the facility inventory database.

— Calculation data specific for decommissioning activities, including parameters of techniques and processes (workforce, costs and consumables unit factors), working group data;
— Work difficulty factors;
— Waste data.

8.2.1. General data

This group of calculation data contains mainly unit cost factors. The first part of the unit cost factors are the labour unit cost factors (salaries and wages) of individual skills of the working groups expressed as currency per hour. It involves the payments paid by the company to employees and charges to various funds, such as social security contributions, insurance, social charges and other charges paid by the company and, lastly, the overheads specific for a given project, which can be calculated in relation to personnel. The data are expressed as percentages added to salaries paid by the company performing the decommissioning activities. Labour unit cost factors are the main national specific data.

The second part of the unit cost factors represents the unit cost factors for consumables, such as electricity, steam, fuel oil, air, chemical substances and other substances and materials used by technological procedures within the cost calculations expressed in currency per specific unit of the relevant media (e.g. kW·h, m^3, kg).

Other general parameters used in the calculations are the general data related to working time, such as work days per year, work hours per shift and others.

Radiological data such as the background dose rate in the facility and decay coefficients for the main radionuclides that are used in the selection of options for deferral of decommissioning also form part of the general data.

8.2.2. Data for activity dependent costs

8.2.2.1. Unit factors

This type of input data characterizes and quantitatively describes the individual decommissioning activities from predismantling decontamination through dismantling, waste management and up to the disposal of waste packages. The extent of the activities included in decommissioning cost calculations depends on the scope of the given decommissioning project, the level of detail of the project and the waste management scheme of the project.

The calculation parameters for individual decommissioning activities are used for the calculation of the costs and other decommissioning parameters together with the data in the inventory database. Calculation data for the decommissioning activities include technical, economic and working group parameters.

Technical and economic parameters define the essential features of the given decommissioning activity. The main parameters are:

- Unit workforce factors for hands-on activities (manual or remote techniques) for calculation of the amount of work depending on data from the inventory database.
- The capacities of equipment and technology used in waste management.
- Unit consumption factors, including consumption of electricity, steam, fuel oil, air, chemical substances, working tools and equipment, etc.
- Unit investment factors for the consumption of materials and spare parts in the case of large technological equipment used especially in waste management. In addition, the degradation factors when the calculation of costs is performed on the basis of the amount of input materials to be processed.
- Non-specified expenses, including the unit cost factors expressing the cost for specific items entering the process as defined individually (electricity, steam, fuel oil, air, chemical substances, working tools and equipment, etc.). The parameter involves all other inputs, as listed above, to the processes not evaluated individually.
- Non-specified investment cost, using the same approach as in the case of non-specified expenses but related to items with an investment character. These items may have quite large values, especially in the case of permanent, large equipment (such as for the waste management techniques) when costs are calculated on the basis of the number of input variables.

Working group parameters include the assignment of a working group to individual activities. Working groups consist of individual skills. Each skill in a working group has a number of assigned workers. Normally, there are several representative skills represented in a working group. An example is given as follows:

— Manager — personnel at a managerial level;
— Senior engineer — experienced graduate engineer with approximately 10 years of experience;
— Engineer — standard graduate engineer;
— Technician — qualified operator in a relevant discipline with non-graduate, secondary school education;
— Administrative worker;
— Skilled worker — qualified craftsman;
— Auxiliary worker — semi-skilled worker;
— Nominal skill as an alternative for any of the seven skills listed above.

The skills listed above are used for the composition of working groups for individual decommissioning techniques and waste management activities and also for definition of the specific composition for period dependent activities. At the preliminary costing stage, the representative skills listed above can be replaced by an average level of skill or, in the case where there are difficulties, used for identification of a requisite skill.

It is convenient to organize the data for individual decommissioning techniques, including the waste management techniques, into the form of datasheets for each individual decommissioning activity.

8.2.2.2. Work difficulty factors

Individual working groups for hands-on decommissioning activities need non-effective working time components to be considered to reflect the time required for preparing and supporting the execution of work for the given decommissioning activity. Such considerations include the entry of workers into controlled areas, breaks in work, movement of personnel during working time within a controlled area, exit from a controlled area, etc. These non-effective working periods are normally expressed as percentages related to the calculated working time, i.e. 'work difficulty' factors. The non-productive time components are defined for work within the controlled area and outside of the controlled area. Other types of 'increase factor', which prolong the duration of individual working, are related to constraints to personnel that differ from ideal working conditions. Examples of these increase factors are:

— Work in areas with dose rates that modify the working sequence in order to keep the exposure ALARA;
— Work when using personal protective equipment (respirators or protective overalls with additional air for breathing, which lower the work rate);
— Work at heights on scaffolding, which requires additional supporting activities in order to achieve the desired result;
— Work on complicated tasks, e.g. where the sequence of performing decommissioning activities requires additional ad hoc solutions to perform the given activity.

These data are contained in the calculation database mostly in the form of 'interval functions'; these define the work difficulty factors for selected parameters contained within the inventory database.

8.2.3. Waste data

Waste data is prepared prior to calculation and estimated on the basis of the content of the physical inventory and the radiological properties of individual inventory items. Specific input data for individual techniques and procedures for waste management are required in the current costing methods. Limits and conditions are considered for selected waste management techniques that determine the material flow in the decommissioning process, such as the limits and conditions for release of material, for disposal of waste and the parameters of the waste management techniques.

As a result, the waste amounts are estimated as the input data for each waste management activity involved in the overall waste management scheme for a given decommissioning project (Figs 3 and 4). Waste items should be defined for each decommissioning option individually. Waste generated during decontamination and dismantling activities may have the following forms:

— Primary waste;
— Secondary waste;
— Interim forms of waste;
— Waste forms for disposal;
— Materials for release.

In some costing methodologies, the modelling of material and radioactivity flow in the calculation process is combined with a dynamic radiological recalculation, i.e. a re-evaluation of radiological parameters according to the start time of the activity due to the radioactive decay of individual radionuclides. This can increase the accuracy of the cost calculation for waste management, especially in cases of facilities with a non-standard radiological situation (e.g. after accidents) or in the case of decommissioning options with phases for deferred dismantling.

8.2.4. Input data for period dependent activities and for collateral costs

The basic set of input data for the calculation of costs and for other decommissioning parameters is organized in the facility inventory database and in the database of calculation data. These two groups are prepared for general use for all calculation items and for all decommissioning options. The third group of data includes the data defined for individual calculation items. These data are not organized in a general form such as the databases, but are normally defined individually for each calculation item. They are based on the data from the inventory database using selection criteria and the results of interim calculations and normally introduced by the user as keyboard data. Typical input calculation data of this type are:

— Data for defining the working groups and durations of period dependent activities;
— Workforce optimization data;
— Collateral cost data;
— Specific inventory data;
— Specific waste data.

The definition of working groups for period dependent activities is specific for individual calculation items and should be defined individually for the skills in the working group and for the number of individual skills and the duration of activities. Additional data can be defined for the calculation of dose to workers.

Workforce optimization data are data for management of the duration of decommissioning activities by the definition of the number of working groups and the number of working shifts. In this way, the critical paths in the decommissioning time schedule can be managed.

Collateral cost data are related to fixed and period dependent cost items that can be identified as items specific to the given decommissioning activity. These data are used for introducing the fixed cost items, such as procurement of equipment, or as additional specific cost items for any decommissioning activity.

In some cases, the calculation items are used for the ad hoc adjustment of calculation cases where the inventory data or waste data are not available. In these cases, the user directly at the level of the calculation items defines the input data.

9. COSTING APPROACH BASED ON IMPLEMENTATION OF THE ISDC

This section describes the main general principles of the ISDC costing model and its implementation; costing methodologies for individual cost types, as identified in Section 6.3 (hands-on activities, period dependent activities and fixed costs), and the procedures and types of calculation algorithm; practical steps in cost calculation, such as preparing the input data for calculation of cost and other decommissioning parameters; calculation of costs; management of calculated data and management of decommissioning options. The information in this section is the basis for development of the ISDC cost estimation model for individual decommissioning cases.

9.1. COSTING MODEL BASED ON THE ISDC

The general ISDC costing approach is presented in this section by describing the methods of implementation of the bottom-up principle and the implementation of the ISDC as the basis for the calculation structure and for describing the relations between the main structures involved in the proposed costing approach. The general costing model presented in this section is the basis for the specific costing model for research reactors for the preliminary costing stages with a limited extent of input data. The model is proposed and presented in Section 10.

9.1.1. Costing approach based on implementation of the ISDC as the cost calculation structure

There are two principal methods for implementation of the ISDC structure [4]:

(i) Use of the ISDC structure for mapping of cost data from costing structures based on a WBS;
(ii) Use of the ISDC as the cost calculation structure.

The first approach is used in cost calculation structures developed before the ISDC was introduced to the decommissioning costing community in 1999 as the interim version of the standardized cost structure [3] and, currently [4], as the structure upgraded based on 10 years of experience of its application. Existing cost calculation methodologies, which are based mostly on the WBS for decommissioning projects, use the approach of mapping WBS items at the lowest level to ISDC items at the third numbered level. The ISDC third numbered level is considered as the reference level for presenting the decommissioning cost; the first and second ISDC numbered levels are the aggregating levels.

In the second approach for implementing the ISDC into decommissioning costing, the ISDC structure is broken down into levels lower than the third ISDC numbered level down to the level of individual elementary decommissioning activities that are the subject of the cost calculation. In fact, this is the implementation of the bottom-up approach. Extension may be performed by adding additional levels numbered by additional ISDC numbers, or may be indexed by other additional indexes representing, for example:

- The structure of buildings, floors and rooms of the facility to be decommissioned;
- The systems of the facility;
- The construction subassemblies of complex structures such as the reactors.

There is large flexibility in developing the ISDC based cost calculation structure. Automation of the generation processes for ISDC based cost calculation structures facilitates this approach [17]. The main features for implementing the ISDC as the cost calculation structure are presented in this section as follows:

- How to develop the ISDC based cost calculation structure;
- How to organize the cost calculation process for the ISDC cost calculation structure;
- Presenting the decommissioning costs in ISDC format.

Information presented in Section 9 is the basis for development of the costing model for research reactors at the preliminary costing stages. The costing model for research reactors based on the ISDC structure is presented in Section 10.

9.1.2. Principal scheme of the ISDC costing model

The summary of the proposed costing approach, as presented in Section 6, is as follows:

- For calculation of decommissioning parameters, the ISDC [4] is proposed. The ISDC involves all types of decommissioning activity and is proposed as the universal harmonized calculation structure for any calculation case.
- The specific structure of decommissioning tasks is defined in the WBS of the given decommissioning project.

— Unique relations should be established between the ISDC calculation structure and the WBS of the calculation case in order to be able to keep the harmonized structure for processing the calculated data and to keep the project specific task structure.
— The calculation approach is the multioption model that presumes the set of common data used for all calculation cases of the given decommissioning project and the data specific for the calculation case at the level of individual calculation items.

These principles ensure that the costs are calculated, processed and presented in ISDC format; this also enables further standardization in the processing of calculated data. Implementation of the ISDC as the core calculation supports the efforts of harmonization in the decommissioning costing. At the same time, the project specific features are maintained, and the structure of decommissioning tasks can be defined independently for any calculation case.

9.1.3. Development of the ISDC cost calculation structure

The ISDC is used as the basis for identifying the decommissioning activities at the level of the elementary calculation items. The ISDC is proposed to be the core of the cost calculation structure and means that the decommissioning activities identified for calculation are ordered according to the ISDC sequence. The level of detail may be extended to any required level. Implementation of the bottom-up principle means that calculation at the lowest level of identified elementary decommissioning activities may be performed depending on the level of decommissioning costing required (preliminary, etc.). Implementation of the ISDC requires the configuration of decommissioning activities according to the ISDC numbers. The basis for numbering in the ISDC costing model levels is according to three numbered ISDC levels, and may be extended using groups of two digits [17] as follows:

ISDC level '10',	04
ISDC level '100'	04.06
ISDC level '1000'	04.0601
ISDC level '1000.xx'	04.0601.01
ISDC level '1000.xx.xx'	04.0601.01.01
ISDC level '1000.xx.xx.xx'	04.0601.01.01.01
etc.	

The additional ISDC numbering below the three numbered levels is open for downward extension by the user. The group of two digits creates enough space for identifying the specifics within any group. In principle, there is the possibility to create 100 numbered subgroups at each level and, if this is insufficient, relevant subgroups may be defined. This approach has the following advantages:

— A common standardized calculation platform is established that is harmonized to the third numbered level for any calculation case.
— Any aspects that are specific for a group of nuclear facilities can be easily harmonized at the lower calculation levels. This is, for example, the case for research reactors as defined within this publication, including small and medium nuclear facilities.
— There are additional possibilities for the development of calculation structures for typical equipment with a complex construction, such as calculation structures for the dismantling of reactors of a given type. In this way, the calculation segments, which can be easy to implement into any standardized calculation structure, can be developed.
— There is no theoretical limitation to the development of the numbered levels downwards. There are some practical limitations for the level of detail for a given decommissioning project and limitations in the software used for development of the calculation structure. In this aspect, some practical limitations may be identified using the Excel spreadsheet software, but there is no limitation, in principle, when using the software for large databases such as ORACLE.

The principles of harmonization presented above have general value in the decommissioning costing process. Implementation of these principles has an impact on decommissioning costing in general, and also for partial programmes, such as the methodology for decommissioning costing of research reactors. When a similar approach is also adopted for other groups of nuclear facilities, the harmonization in decommissioning costing represents a big step forward. Such costing procedures could be harmonized and, at the same time, they could remain specific for selected parts of nuclear facilities. Hence, a database of specific and representative calculation structures could be developed.

Aspects of grading in decommissioning costing are also easy to implement when accepting this approach. The level of detail is easy to adapt for any decommissioning project. For preliminary costing studies, the ISDC level '100' or '1000' (Section 9.6) seems to be sufficient; later, the lower levels may be implemented.

An example of a procedure for the development of an ISDC cost calculation structure is given here [17]:

(a) **First step.** The generic ISDC at the third numbered level represents typical decommissioning activities. At this level, several typical decommissioning activities are allocated general descriptions for each item. These activities are then the subject of definition at the next level(s) lower than the third level. The activities are analysed from the point of view of types of cost category, as hands-on activities, period dependent activities and collateral costs. A general ISDC extended template may be developed, where the period dependent and collateral cost items may be developed as fixed structures with redundant items. The level of depth of the additional levels is variable according to the segments of the ISDC structure and may have two to five additional levels. For hands-on activities, specific ISDC segments may be defined, which may be extended automatically by a computer code, depending on the content of the facility inventory database (object–floor–room–equipment structure). Several modes of automatic generation for these dynamic segments may be defined.

(b) **Second step.** The general ISDC template is allocated to the given decommissioning option and adapted by the user according to the scope of the option. Adaptation means deleting segments obsolete for the option and adding option specific segments. An option specific 'static' ISDC template is developed at this step.

(c) **Third step.** The option specific ISDC template is used for the generation of the ISDC cost calculation structure for the decommissioning option by interaction of the option specific ISDC template and the facility inventory. Those segments in the static option specific ISDC template, with definitions of how to extend them, based on the facility inventory data, are extended in this step according to the content of the facility inventory database (inventory items in rooms). A full list of the elementary hands-on activities for the project is created here. The generated ISDC cost calculation structure involves static segments for period dependent activities and for collateral costs and dynamically generated segments for hands-on activities according to the room oriented structure of the facility inventory database. System oriented segments [5] are a mix of static parts and dynamically generated parts.

The proposed approach in developing the ISDC cost calculation structures is easy to adapt in relation to grading the decommissioning costing. At the stage of preliminary costing studies, where the extent of calculation items can be at the level of approximately hundreds of calculation items in the case of small and medium nuclear facilities, the ISDC calculation level could have the level ISDC 100 for period dependent activities and the ISDC 1000.xx for hands-on activities. At the stage of detailed cost studies, the calculation level for period dependent activities may be ISDC 1000.xx up to ISDC 1000.xx.xx.xx and more for hands-on decommissioning activities.

9.2. COSTING METHODOLOGY SPECIFIC FOR THE ISDC

9.2.1. The ISDC costing approach

As for the calculation approaches, the ISDC costing approach is the same, in principle, as used in existing costing methodologies, i.e.:

— Respecting the cost types as activity dependent, period dependent and collateral costs;

— Implementing the bottom-up approach;
— Implementing the unit factor approach.

Some differences may be found in the calculation details and the sequence of the calculation. Owing to the obligatory structure of ISDC cost categories (labour costs, investment, expenses, contingency), the calculation sequence starts with the calculation of workforce for all types of decommissioning activity; workforce items are evaluated for all skills involved in the working groups. Workforce is the basis for the calculation of labour costs individually for each skill within the working group for an elementary decommissioning activity.

Investment items and items of expenses may be calculated in several ways using the unit factor approach. Also, in order to be able to present these items in ISDC format, parallel to items of cost categories, it is convenient to calculate these cost items in two steps:

(i) Calculation of the consumption of investment items and expenses using the unit factors for individual consumption items (kW·h, m^3, kg, piece, etc.);
(ii) Calculation of costs for individual items based on the calculated quantities in the first step and on the unit cost factors for individual items.

A single step calculation approach is used at the preliminary costing stages. Overall cost unit factors for investment costs and for expenses are used in this case. These types of unit factor include all items relevant for investment and for expenses according to the ISDC definitions.

Contingency may be calculated in various ways. In the ISDC approach, the contingency is evaluated at the lowest calculation level as part of the calculation sequence for individual items. The level of detail may be different, but the calculation remains at the lowest calculation level.

This approach enables the availability of cost data for all ISDC cost categories at the lowest calculation level.

9.2.2. Calculated parameters

9.2.2.1. Decommissioning parameters

For the planning of decommissioning activities, the main decommissioning parameters for evaluation are:

— Costs;
— Workforce;
— Dose to workers;
— Duration;
— Number of personnel;
— Waste items;
— Technical media for processes;
— Machinery and equipment for processes.

Cost is the main decommissioning parameter. All aspects, input data, factors affecting the decommissioning strategy, processes and individual decommissioning activities are transformed into decommissioning costs. The main cost drivers are the elements of the selected decommissioning strategy, defined by the decommissioning scenario, techniques, facility end state and applicable waste management issues. The strategy defines the extent of decommissioning activities and relevant techniques and personnel, as defined in the decommissioning plan. Until the publication of the interim standardized structure [3] and the ISDC [4], decommissioning projects had, and still have, different structures. The approach selected in this publication is the implementation of the ISDC in order to promote the harmonization of decommissioning costs.

Workforce is the relatively neutral decommissioning parameter. Workforce reflects the amount of work performed within the decommissioning project. It is the main indicator of the size of the project. Costs for the same amount of work can vary markedly for various national conditions, but the extent of workforce remains similar. In the approach adopted in this publication, workforce is the base for the calculation of cost and other decommissioning parameters, such as duration, exposure, etc. Workforce items represent the real amount of work performed under given conditions at the facility.

Dose to workers is the main safety related parameter. Dose reflects the radiological conditions in the facility undergoing decommissioning. The dose rate during the individual decommissioning activities, especially dismantling, has an impact on the amount of work and also on cost by prolonging the activities, implementing additional safety measures or implementing remote controlled techniques. The dose to workers plays an important role in considering a deferred decommissioning strategy. A cost versus saved sieverts analysis may be performed if tools are available to support evaluations or sensitivity analyses.

Duration is the main planning parameter that considers the time aspects of a decommissioning project. The calculated durations of relevant individual elementary activities within the basic project tasks are aligned to form the durations of project tasks at the lowest level. At higher levels, the tasks are aligned and linked to form the decommissioning schedule. The hands-on decommissioning activities are used to develop the critical path in the decommissioning schedule, and the period dependent activities are adjusted to this critical path.

Number of personnel is the main parameter for the planning of human resources. It is calculated at the level of individual elementary decommissioning activities and aggregated as the total number of workers required for the project or for phases or subtasks of a project. At the level of the individual, the calculation can be resolved to the individual skills required in the processes.

Waste items are used for the planning of waste management processes. Waste items data are normally estimated prior to the calculation of the parameters for waste management processes. There are also codes that calculate the waste items data on-line in the calculation process using the system for modelling the flow of material items and the flow of radioactivity linked to material items [18].

Consumables and spare parts for processes are calculated as consumable items for individual processes. The calculated data are used for planning the delivery of consumables to processes. Examples of main consumables are electricity, technical water, desalinized water, steam, gasoline, spare parts, etc.

9.2.2.2. Grading the extent of decommissioning parameters

The extent of the calculated parameters and level of details of the individual parameters are the subject of grading from the preliminary costing stages up to detailed calculation at the stage of the final decommissioning plan. At the preliminary levels, cost may be the only parameter of interest; later, the workforce data are included: duration, dose to workers, etc. At the final stage, all the above listed parameters may be evaluated.

9.2.3. Costing approaches for individual decommissioning parameters

The experience from current decommissioning costings shows that, in order to present all ISDC cost categories for all calculation items, the calculation of workforce components of individual elementary decommissioning activities is recommended as the first step. The workforce components can be assigned to the individual skilled personnel performing the elementary decommissioning activity. On the basis of this, the labour cost and the dose to workers can be evaluated. The costs are completed as the process cost identified as investment cost and expenses for the individual process and, finally, by including contingency.

Calculation of workforce is different for hands-on (activity dependent) activities, for waste management activities and for period dependent activities. The workforce for activity dependent decommissioning activities is calculated as total workforce as the product of the input inventory value (mass, surface, volume, etc.) and the workforce unit factor for the individual decommissioning category, such as the dismantling of 1 t of pipe of a given category, or decontamination of 1 m^2 of the building surface by chemical decontamination, etc. Workforce components are increased in the calculation for non-productive time components defined for within or outside of the controlled area. Additional workforce is calculated, where relevant, using work difficulty factors due to working in radiation fields, working at heights, use of remote controlled techniques, etc.

Workforce for period dependent activities is calculated as the sum of workforce components calculated as the product of the duration and the number of personnel for individual skills. This procedure is also used for the calculation of workforce for waste management activities, where the duration is calculated as the product of capacity of the given technology and the amount of input material.

For preparation and finishing activities used in room or system oriented approaches, the workforce components are defined normally as fixed values, taken from the database of parameters of preparatory and finishing activities, and in some cases adapted for the size of the room.

The workforce components for individual skills of the working group are calculated as components proportional to the number of workers for individual skills within the working group. These workforce components related to individual skills are the basis for the calculation of labour cost for individual elementary decommissioning activities.

9.2.3.1. Costs

The selected approach implements the calculation of cost elements according to the ISDC definition at the lowest calculation level. The cost categories, as defined in the ISDC structure, are as follows:

— Labour costs;
— Investment costs (capital, equipment and material costs);
— Expenses;
— Contingency.

Labour costs represent the costs of staff involved in the evaluated activity. The calculation of labour costs is performed based on the calculation of components of workforce for individual skills of the working group multiplied by labour unit cost factors for the individual skills of the working group and summed over the skills of the working group. For activity dependent costs, the workforce components are calculated from the total workforce, in proportion to the composition of the working groups. For period dependent costs, the workforce components are calculated from the duration of the elementary activity and the number of workers in the working group. The labour unit cost factors for each skill have three main components [4]:

— Payments to employees;
— Social security contributions, insurance contributions, social charges;
— Overheads.

Payments to employees are normally derived from the actual payment for the relevant skill in the nuclear industry of the given country. The values of social security and insurance charges and contributions are defined by the national laws and by trade or other specific agreements within the companies involved in decommissioning. The overheads are specific for the given project. The full definition of the labour cost components is presented in Ref. [4]. Depending on the grading of the cost calculations, the above listed items can be implemented as one or several calculation items.

Overheads are added to labour costs in general. In the costing approach, where all personnel involved in the process are identified and relevant labour costs are calculated, the overhead costs involved in employment are added to the labour costs. Overheads are calculated normally as a percentage related to the labour unit cost factors.

Investment costs (capital, equipment and material costs) represent the costs of procurement of equipment or machinery used for dismantling, decontamination, demolition and other activities, the costs of technological equipment for processing and conditioning of waste and the costs of materials, spare parts, protective clothing, etc. National laws define the limits on the costs of items of materials and spare parts when considering them as investment costs. Investment costs are introduced as fixed values into the calculations (as keyboard data) or by using unit cost factors that include items such as depreciation or deterioration of equipment, consumption of materials and spare parts.

Examples are purchased items such as cranes, trucks, forklifts, excavators, demolition hammers, etc. Some of these items may be resold for cost recovery when the project is completed. Material costs are for consumables, spare parts, protective clothing, etc. The costs of these items exceed the limit defined by national accounting principles.

Expenses represent the costs for material and consumables used in the decommissioning process. Expense calculations are based on input variables (weight, surface, volume, etc.) and specific unit factors for consumables used in processes or individual equipment. Expenses may be structured as expenses for general technological consumables, such as electricity, water, steam and others; expenses for specific consumables for individual processes, such as technical gases, cement, bitumen and others; and expenses for spare parts of a non-capital character and non-technological expenses. Other examples of expenses, such as legal fees, tax, insurance, consulting fees, rent, office materials, utilities and others, are mostly considered as collateral costs.

Contingency is added to calculated cost elements in order to allow specific provisions for unforeseeable elements of cost within the defined project scope. In order to distinguish the nature of contingency, it may be calculated by two methods: (i) by the calculation of contingency for the individual cost items listed above using identical percentage values for the whole calculation option (calculation of contingency for costs of labour, for investment costs and for expenses, i.e. as a percentage applied in aggregate) and (ii) by applying a contingency specific to individual calculation items that may differ in the calculation structure, based on a specific uncertainty for the given calculation item.

The original standardized structure of cost items for decommissioning [3] also contained special contingency items related to areas of higher uncertainty (item 11.0700 of the standardized list of cost items). These items are no longer considered in the ISDC [4] owing to the fact that these items represent costs that are out of the scope of the project and are evaluated and presented outside of the ISDC format.

Contingency costs are for unforeseen, uncertain and unpredictable conditions typically encountered in decommissioning. In general, all contingency costs are spent as the project progresses, as these unforeseen events occur throughout the project.

Total cost per calculation item is calculated as the sum of labour costs, investment costs, expenses and contingency.

Dose to workers is dependent on the duration of the decommissioning activity in a given radiation field on the basis of the time spent in the radiation field for the individual skills employed. The exposure of personnel for individual skills is calculated as the product of the workforce components for the individual skills of the working group and the dose rate and the exposure coefficient for the given skills.

The exposure coefficient reflects the fact that the individual skills within the working group spend different times in the radiation fields while performing the decommissioning activity. The total collective dose equivalent for the given decommissioning activity is the sum of dose equivalent components for each skill of the working group.

Safety related parameters have an impact on the cost of decommissioning. As an example, to maintain the limit of exposure of individuals, remote techniques may be used. However, these may prolong the duration of the work, and the techniques are, in general, expensive to apply.

Advanced decommissioning calculation methodologies calculate the dose at the level of individual members of the working groups. The calculated data are then used for the application of the ALARA principle in the safety evaluation of critical decommissioning operations in order to meet safety criteria, such as the annual dose limit for individuals.

9.2.3.2. Other decommissioning parameters

Duration of individual elementary decommissioning activities is calculated by dividing the total workforce of the activity by the total number of workers involved. The duration of individual activities is the basis for the development of mutual links and the time structure in the decommissioning schedule.

Calculation of the **number of workers** per individual decommissioning activity is the sum of the number of workers per individual skill in the working group. The calculation takes into account the number of working groups and the number of working shifts, if they are considered in the given calculation item.

Waste items are normally calculated prior to the calculation of costs of processing. The waste data include all primary waste generated during the decontamination and dismantling, and all secondary and interim waste and waste for disposal. The costing methodologies calculate the primary waste items based on the facility inventory data, and all secondary, interim and final wastes are the result of properly sequenced calculations that simulate the flow of materials and radioactivity in the project [17].

Consumables for processes are calculated based on consumption unit factors for individual consumption items. The purpose of these calculations is to provide data for the planning of decommissioning activities and to provide the data for an environmental impact assessment of the planned decommissioning activities.

9.3. ASSESSMENT OF ACTIVITY DEPENDENT COSTS

9.3.1. Categorization of inventory items

According to the classification of cost categories, the activity dependent costs are directly related to the extent of 'hands-on' work involved in decommissioning. They include activities such as decontamination, removal of components and waste management activities. Costs arise from labour, materials, energy, equipment, services and specific items related to waste management. The cost is directly related to the input variables, which, in general, are the masses, areas, volumes, number of pieces, etc., using the calculation principle of unit factors. Implementation of this principle means that the calculation of workforce and other parameters, such as the consumption of technical media or other expenses or investment items, are directly related to the properties of the inventory items.

This direct relation to the input variables gives rise to implementation of the principle of categorization of items contained in the inventory database. Size, construction and material composition give rise to different unit factors for different equipment to be dismantled. Unit factors are similar for equipment with similar properties and can be very different for equipment with different constructions. As an example, the workforce required for dismantling pipes with the same weight, but with small diameters and thin walls, can be several times higher than for dismantling pipes with large diameters and thick walls. The reason is that different amounts of work are required for the normalized input variable, in this case, 1 t of pipes.

Owing to the fact that a large proportion of various types of equipment can be identified in a nuclear facility, the principle of categorization has proven to be effective in decommissioning costing. The principle is based on the grouping of types of inventory item with similar properties into one group, for which the unit factors are defined.

Another aspect of the implementation of the principle of categorization is the selection of the relevant decommissioning technique for a given category. Various techniques have different properties and consequences in decommissioning costing, but there are different unit factors for the various techniques. The selection of the optimum decommissioning technique for a given decommissioning category is an important issue in decommissioning costing.

Decommissioning category is one of the key parameters in decommissioning costing. This approach enables a reduction in the volume of data required for decommissioning costing. For comparison, during the operation period, the data need to be maintained for every type of equipment. These operational data are one of the sources for development of the decommissioning data.

The decommissioning data relating to the decommissioning category, which are used in implementation of the unit factors approach, include data that have specific values relating to the normalized input variables (mass (t), area (m^2), volume (m^3), etc.), such as:

- Workforce for performing the decommissioning activity;
- Consumption unit factors for technical consumables;
- Consumption unit factors for spare parts and tools;
- Unit cost factors involving expenses other than identified consumption items;
- Unit cost factors for investment costs.

9.3.2. Unit factors

9.3.2.1. Workforce unit factors

Workforce is the total effort of all members of the working group required for performing a given decommissioning activity under predefined conditions. As an example, the workforce unit factor for dismantling pipes of the category 'Pipes 2 CS' is the workforce required for dismantling 1 t of pipe made of carbon steel (CS), with a diameter ranging from 100 mm to 250 mm; the cutting length of 1.5 m being the longest dimension of the waste transport container. The workforce unit factors include all activities, starting with the cutting and ending with the placement of the material into the transport container.

The workforce unit factor also takes into account the fact of whether the inventory item to be dismantled is located within the controlled area or outside of the controlled area. When situated within the controlled area, the sequence and structure of decommissioning activities should also include all elements of working activities relating to the safety of work with radioactively contaminated materials and associated radiation fields. This means that the aspect of radiation protection against the external and internal exposure of workers should be considered. This is one of the reasons why the workforce unit factors differ to a large extent for dismantling within and outside of the controlled area for the same mass and the same equipment.

Other reasons for differences in workforce unit factors are the conditions for performing the decommissioning activities. When dismantling within the controlled area, segmented materials should undergo sorting and subsequent waste processing, and the size of the segmented material should enable measurement and processing. In the case of dismantling outside of the controlled area, the segmenting of materials into larger pieces can be performed. These approaches require different amounts of work that result in different workforce unit factors.

Workforce unit factors are defined separately for decommissioning activities performed remotely. The extent of the activities involved is larger, productivity factors are, in principle, lower owing to the nature of the techniques, and the number of personnel and qualification requirements are higher. These are the reasons that the workforce unit factors are five to ten times higher compared with manual techniques.

Workforce unit factors are defined for decommissioning activities for which the input variable can be defined in the facility inventory database. Examples of these activities are:

- Dismantling of the main technological systems, such as reactors and primary and secondary components that are specific for the decommissioning project;
- Dismantling of auxiliary systems of a general nature;
- Dismantling of contaminated and activated structures, such as reactor shafts, concrete biological shielding, embedded elements;
- Decontamination of building surfaces;
- Radiological monitoring of building surfaces.

For some repetitive decommissioning techniques, which are performed under the same conditions and represent the same amount of work, the workforce unit factors are constants, for example, the preparatory and finishing activities as implemented in the room oriented dismantling approach (see Section 7.3).

9.3.2.2. Other unit factors

Consumption unit factors for technical consumables represent the quantity of consumables required for performing a given decommissioning activity for a normalized quantity of the input variable. An example is the quantity of technical gases required for the cutting of 1 t of equipment of a given decommissioning category or the quantity of electricity required for the electrochemical decontamination of 1 m^2 of a stainless steel surface. A similar approach is used for the calculation of spare parts and tools for individual techniques. The identified consumption unit factors for technical consumables and for spare parts and tools cover only part of the cost incurred in using a given decommissioning technique. In order to calculate the complete cost, the rest of the costs can be expressed as the unit cost factors involving all expenses other than the identified consumption items. A similar approach can also be implemented for the calculation of investment costs, by defining the unit cost factors for investment cost per individual technique or technology.

9.3.2.3. Grading aspects in the unit factors approach

The principle of decommissioning category can be easily graded. At the initial or preliminary levels of decommissioning costing, the workforce unit factors are developed for several typical categories. Other unit factors for these categories can be developed as the overall unit cost factor covering other labour costs. This approach enables calculation of the workforce uniformly at all stages. Later, at the conceptual levels of decommissioning costing, the extent of unit factors can be gradually extended for a limited number of decommissioning categories. Finally, at the level of detailed decommissioning costing, the extent of unit factors and number of decommissioning categories can be developed to the final level of detail, depending on the size and complexity of the facility to be decommissioned.

9.3.3. Decommissioning techniques

The principle of categorization can be organized into practical decommissioning costing according to Table 1 [5], which represents the example of allocation of dismantling techniques (horizontal direction of the matrix) to individual dismantling categories (vertical direction of the matrix). The techniques applicable for the given category are the optimum techniques, presented in green, and other applicable techniques, presented in blue. The unit factors approach requires that for all the combinations presented in Table 1, unit factors should be developed. The table shows an example of the categorization of technological equipment used for the calculation of the cost of dismantling. The same approach can be used for categorization of other elements of the inventory database as the main cost drivers in decommissioning techniques, such as for:

— Building surfaces for decontamination and for final radiation survey. The surfaces are categorized to enable the selection of the appropriate decontamination technique (chemical or mechanical as the main techniques) and the surfaces for radiation monitoring.

— Materials of the civil structures. The main types of material and appropriate techniques for demolition should be considered, such as for reinforced concretes (several categories should be defined depending on the thickness of concrete walls), plain concrete, masonry, panels, etc.

TABLE 1. ALLOCATION OF TECHNIQUES TO SELECTED DISMANTLING CATEGORIES

Dismantling category	HDCT	COBO	PLSM	OCHC	MSW	OACT	PLHC	MNOC	MAND	MAPL	GROC	GRPL
Piping (SS), diameter =< D25 mm												
Piping (SS), diameter over 25 mm												
Piping (CS), diameter =< D25 mm												
Piping (CS), diameter over 25 mm												
Tanks (SS)												
Tanks and containers (CS)												
Heat exchangers (SS)												
Heat exchangers (CS)												
Pumps (SS, CS), mass <= 50 kg												
Pumps (SS), mass over 50 kg												
Pumps (CS), mass > 50 kg												
Ventilators (SS, CS), mass <= 50 kg												
Ventilators (SS), mass > 50 kg												
Ventilators (CS), mass > 50 kg												
Valves (SS)												
Valves (CS)												
Electric motors, mass <= 50 kg												
Electric motors, mass > 50 kg												
Air conditioning components – piping (SS)												
Air conditioning systems others (SS)												
Air conditioning components – piping (CS)												
Air conditioning systems others (CS)												
Air conditioning systems (Al)												
Electrical cables & conductors												
General electric equipment (CS), mass <= 50 kg												
General electric equipment (CS), mass > 50 kg												
Thermal insulations, non-metal covering												
Steel constructions (CS)												
Small piece components, shielding (CS)												
Hoisting equipment (CS), electrical tackles												
Digestors, sampling boxes (CS)												
Piping feedthroughs, gulleys												
Hermetic and shielding doors (CS)												
Stainless steel linings (SS)												
Carbon steel linings (CS)												
Other general equipment												
Casing of technological equipment (CS)												
Casing of technological equipment (SS)												

PLSM	Release factor = 10 %
OCHC	Release factor = 1 %
HDCT	Release factor = 0,1 %

Note: CS: carbon steel; SS: stainless steel; HDCT: hydraulic shears cutting; COBO: core boring; PLSM: plasma cutting; OCHC: oxygen cutting–hydraulic cutting (combined technique); MSW: mechanical cutting by saw; OACT: oxygen cutting (oxygen-acetylene cutting); PLHC: plasma cutting–hydraulic cutting (combined technique); MNOC: manual dismantling–oxygen cutting (combined technique); MAND: manual dismantling (by tools); MAPL: manual dismantling–plasma cutting (combined technique); GROC: grinding–oxygen cutting (combined technique); GRPL: grinding–plasma cutting (combined technique).

The example presented in this section shows that the principle of categorization is the universal approach adapted for various levels of costing. The grading in categorization means that the representative categories should be developed for the given level of decommissioning costing. As an example, for preliminary costing studies, several categories (typically less than ten) are sufficient for the calculation of the parameters for dismantling; for the intermediate levels, approximately 20–25 categories are typical, and for detailed costing, the extent of categories could range from several tens up to approximately 100.

9.3.4. Sequence of calculation for activity dependent costs

For hands-on activities, workforce is the driving element for decommissioning costing. Workforce is determined by the following main factors:

- Input variables taken from the facility inventory database, e.g. mass of equipment in the decommissioning category to be dismantled, area of building surfaces to be decontaminated, mass of the building structure category to be demolished;
- Unit factors for the relevant decommissioning activity;
- Non-productive working time components that prolong the overall duration of the decommissioning activity;
- Work difficulty factors representing the conditions for performing the decommissioning activity.

The principal calculation sequence is the same for all stages of decommissioning costing from the preliminary stages up to the detailed final cost calculation. It includes calculation of workforce, duration and cost groups as the main data in all stages of the calculations. In more detailed calculations, other data are included, such as dose to workers, calculation of consumption items and others. In principle, the main steps are equal for all calculation stages. The general calculation steps are as follows:

- Calculation of workforce as the product of the input variable taken from the inventory database and the workforce unit factor according to the decommissioning category of the inventory item. The result is the basic workforce corresponding to working in ideal conditions and performing the work without breaks. The basic workforce includes the workforce of all members of the working group.
- Increasing the workforce for non-productive working time components. The simplest method is to add additional workforce, which is expressed as a percentage of the basic workforce.
- Increase of the workforce for working in non-ideal conditions. The calculation procedure is the multiplication of the workforce (enhanced for non-productive working time components) by work difficulty factors relevant for the calculation item (e.g. working in protective clothing, working in areas with radiation, work on scaffolding, work in congested areas). A final value for the workforce is then achieved.
- The duration of the elementary hands-on activity is calculated by dividing the calculated workforce by the total number of members in the working group.
- The distribution of the calculated workforce to the individual skills of the working group. In simple cases, or at the preliminary calculation stage, the working group has one 'averaged' skill. In the detailed calculation, several skills with various labour costs are considered.
- Labour costs are calculated as the product of the workforce per skill and the labour unit cost factors, which can be defined as one figure or several unit cost factors, depending on the level of detail in the costing.
- Depending on the level of detail of the cost calculation, investment costs are calculated by using one overall unit cost factor or several cost factors that take into account the definitions in Ref. [4].
- The same principle is implemented for the calculation of expenses.
- The contingency, in the case of a preliminary level of costing, can be calculated as one additional cost item defined as a percentage of the sum of the labour costs, investment costs and expenses. In the case of a more detailed level of costing, the contingency may be calculated individually for labour costs, investment costs and expenses, and summed at the end. Additional contingency items may be added to individual calculation items to reflect the level of inaccuracy.

Review schemes of the calculation sequence are presented in Appendix II.

9.3.5. Costing for waste management activities

The ISDC costing for waste management activities should take account of the ISDC items as defined by Principal Activity 05 of the ISDC [4]. The ISDC costing for waste management identifies individual elementary waste management activities as defined in Section 7.3.2. A definition of waste management activities in the ISDC is presented in Fig. 8. The following main groups of waste management activities may be identified:

- Activities related to establishment of the waste management system. Most of these involve the procurement of equipment, construction of buildings, testing, licensing and similar activities. Most of these activities are considered as period dependent activities and as collateral costs and costs for special items.
- Waste processing activities for individual waste types. The definition of ISDC items for waste processing is based on the IAEA classification of waste types [15], with the main steps in waste processing starting from pretreatment up to final disposal of conditioned waste or release of materials and distinguishing between historical, legacy and decommissioning wastes. For each decommissioning project, a detailed waste management system should be defined using schemes of the type presented in Section 7.3.2. Some of the waste management activities presented in these schemes may be considered as a service performed outside the system established and operated within the decommissioning project. Activities of this type are calculated as hands-on activities, with modifications in the calculation of workforce (see below).
- Activities considered as supporting activities for operation of the waste management system, such as operation of auxiliary systems, maintenance, surveillance, radiation protection and other similar activities. Most of these activities are considered as period dependent activities and as collateral costs and costs for special items.
- Demobilization and/or decommissioning of the waste management system operated within the decommissioning project. Most of these activities are considered as period dependent activities and as collateral costs and costs for special items. For dismantling, decontamination and demolition activities, hands-on activities are considered.

There are many possible approaches concerning how to structure the costs of activities related to waste management [4]. In any waste management system, waste streams can be identified in addition to the steps/equipment/techniques for handling the waste. The ISDC reflects both aspects: streams and techniques. The basic structure is organized according to the IAEA waste classification system, as defined in Ref. [15], with the initial items addressing common issues related to the establishment and implementation of the waste management system.

The main steps considered in waste management [4] are treatment (including pretreatment), conditioning, storing and disposal of conditioned/packaged waste or release/reuse of materials. All types of transport between the main steps in waste management must be considered. Characterization is included in each relevant step. Accordingly, the waste management scheme for any decommissioning project can be represented by a matrix structure, with waste streams being represented along the vertical axis and waste processing steps/techniques along the horizontal axis. The main indexing of the ISDC at activity group level (ISDC level 2) is related to waste type; waste processing steps/techniques are identified at ISDC level 3. Indexing at discretionary levels, to represent individual waste management techniques, facilitates the retrieval of data according to these techniques. The structure of Principal Activity 05 thus facilitates the retrieval of the data according to the waste types at the second level and according to the waste steps and techniques at the third level and at the discretionary fourth levels.

9.3.5.1. Calculation procedures for waste management activities

The calculation sequence and procedures for waste management activities are, in principle, the same as those for dismantling activities with modification of the calculation of workforce. The main cost drivers in the waste management activities are the capacities of the individual waste management techniques (processing of quantities of given types of waste per hour), investment costs, costs of specific consumables in the process and personnel for the processes.

Workforce is calculated on the capacity of equipment and the quantity and type of input waste. The resulting duration of operation is multiplied by the number of members of the working groups. Work difficulty factors are

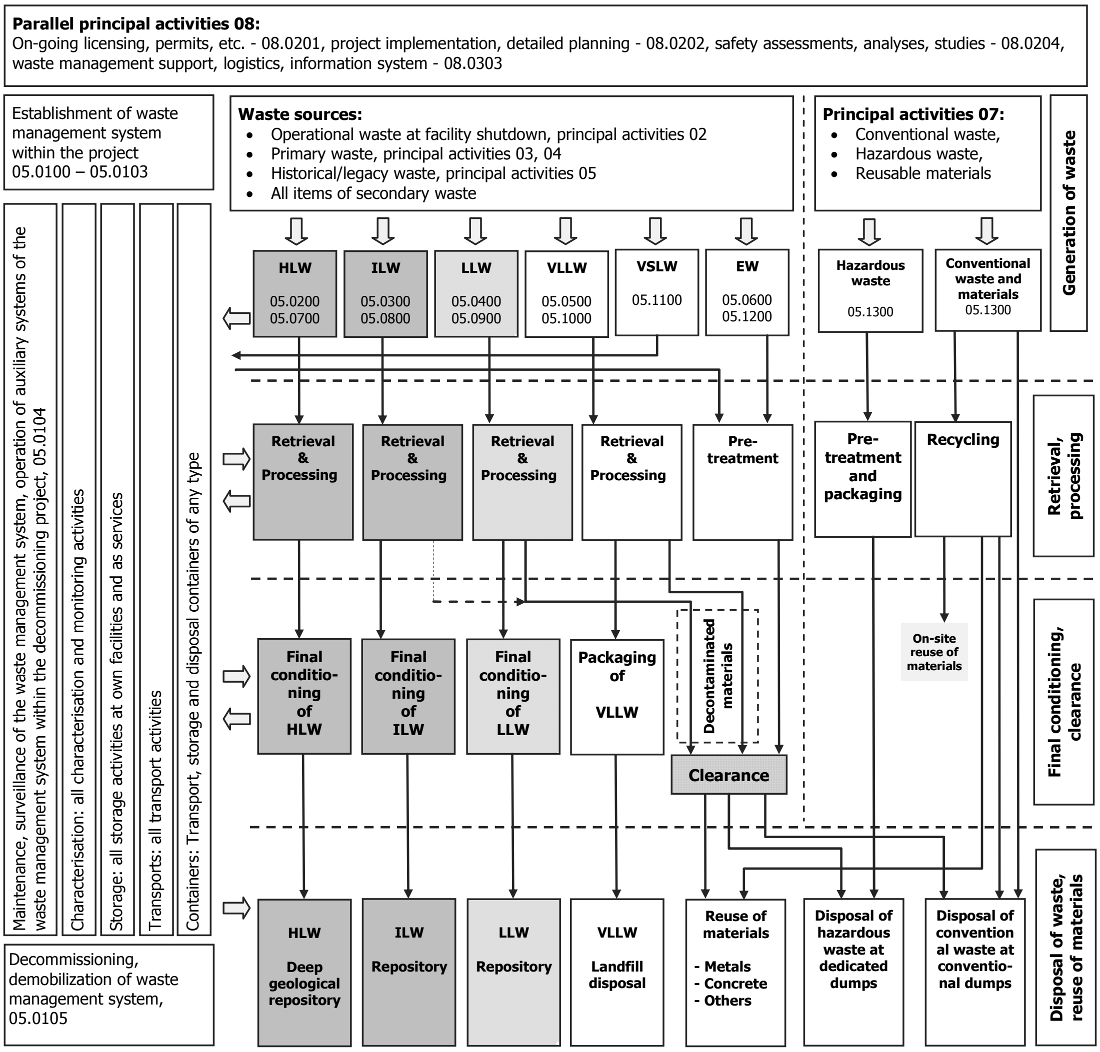

FIG. 8. Principles of organization of a waste management system in a decommissioning project as implemented into the structure of Principal Activity 05 of the ISDC. EW — exempted waste; HLW — high level waste; ILW — intermediate level waste; LLW — low level waste; VLLW — very low level waste.

not considered here; the capacity of the given waste technique involves all productive and non-productive working time components.

Investment costs may be calculated in various ways, depending on the involvement of the waste technique in the waste management system operated within the decommissioning project or considered as a service outside the project. The costs for equipment are considered as one-off costs at procurement, or the investment costs are calculated based on investment unit cost factors and the quantities of input waste for a given waste technique. Expenses are calculated based on consumption unit factors for individual consumables in the process.

Under the decommissioning categories, as considered in costing for dismantling techniques, the individual waste techniques are considered. Unit factors used in the calculation process are related to these individual waste techniques.

9.3.5.2. Grading in costing for waste management techniques

Owing to the complexity of waste management systems, grading plays an important role in the costing for waste management techniques. At the preliminary costing stages, overall unit cost factors may be defined for the main waste type considered in the decommissioning case. As an example, the overall unit cost factors may be defined for ISDC items at level 2. At the detailed costing levels, the costing approach as presented above may be implemented.

9.4. COSTING FOR PERIOD DEPENDENT COSTS AND COLLATERAL COSTS

The main drivers of period dependent costs are the composition of the working group and the duration of the activity. The differences in costing, in comparison with the hands-on activities, are in the calculation of workforce. While the workforce for hands-on activities is calculated as the real workforce required for the performance of an activity, extended for non-productive working time components and increased for various work constraints, the workforce for period dependent activities is the workforce corresponding to the defined duration of the activity. No additional working time components are added.

Workforce is calculated per individual skill in the working group as the product of the duration of the activity and the total number of workers per skill in the working group. The total workforce is the sum of the workforce components per skill in the working group. In simple cases, at the preliminary levels of calculation, one averaged skill may be used. After this step, when the workforce components for individual skills are known, the calculation procedure is the same as for hands-on activities.

Except for the personnel involved, period specific investment costs and expenses may be defined for individual period dependent activities. The resulting costs are calculated as the product of period specific unit factors and the duration of elementary activities. Fixed cost values, when they are part of period dependent activities, are introduced into calculation structures as keyboard data for investment cost, or for expenses.

Some period dependent activities are performed in the controlled area. Dose rates may be defined for these activities, which are the base for the calculation of exposure to personnel, calculated as the product of the dose rate and the duration of the decommissioning activity.

Contingency is calculated as defined in Section 9.2.3, considering the grading in calculation at the various costing stages.

9.5. FORMATS OF ISDC CALCULATED DATA

The calculated cost data should be manageable, at least for the following purposes:

- To organize the cost data into the ISDC format;
- To organize the cost data into the timescale (managing the data in time);
- To link the cost data to items of the decommissioning schedule.

For formatting the calculated cost data (and other calculated parameters) into the ISDC format, the ISDC numbers relevant for individual calculation items are used. Depending on the grading of the costing, the depth of additional ISDC numbering may be different. In order to harmonize presentation of the calculated costs, formatting of the calculated cost data can be organized into three levels: as ISDC 10, ISDC 100 and ISDC 1000, according to the definition presented in Section 9.1.3. Implementation of the ISDC structure into decommissioning costing brings at least two approaches into the formatting of calculated costs:

- The calculated costs have a prescribed structure of cost groups for each calculation item — the total cost and its distribution as labour costs, investment, expenses and contingency.
- The activities of any decommissioning project are formatted according to the ISDC, which means that they are easy to compare with other decommissioning projects.

Formatting the costs into a matrix structure having cost groups in the horizontal direction (with other decommissioning parameters such as workforce, exposure, amount of waste, etc.) and decommissioning activities ordered according to ISDC numbers in the vertical direction (at levels ISDC 10, ISDC 100 and ISDC 1000) should be the standard format for presenting the decommissioning cost data. Organizing the calculated costs in the ISDC matrix (Fig. 9) could then be the common platform for the management of contingency, risk management procedures and other procedures for data processing.

Level 1	Level 2	Level 3	Activity	Labour cost	Investment	Expenses	Contingency	Total cost	User defined data extensions
01									
02									
03									
04									
05									
06									
08									
09									
10									
11									
Total									

FIG. 9. Structure of the presentation platform for the standardized listing of costs [4].

Management of the calculated cost data in time requires formatting the data on a timescale of years. This timescale is used for managing the calculated cost data for decommissioning funding purposes. It means that, except for the nominal values of calculated cost, each calculation item should have additional data that define the position of the calculated data on the timescale. This can be achieved by definition of the start date for each decommissioning activity. The calculated duration then defines the end date of the activity. There are various possibilities for organizing the formatting of calculated data in order to achieve the distribution of cost data on a yearly timescale.

Once the cost data are distributed to years (or, in principle, on any timescale), it is possible to develop graphs or multidimensional tables with data distributed in time.

The relationship to the decommissioning schedule is organized according to the principles proposed and discussed in Section 9.1.2 and in Ref. [17].

Other possibilities for managing the calculated cost data depend on the extent of additional data allocated to the calculated costs. As an example, the cost data can be organized according to the structure of the building objects, if the building object data are available at the level of the calculation item.

9.6. GRADING ASPECTS IN ISDC COSTING

As stated in several sections of this publication, costing at several levels of detail can be identified, starting from preliminary levels, through several conceptual levels, up to detailed cost calculations for the final decommissioning plan. Typical for these levels of costing are the various levels of input data and the extent and detail of the cost calculation structure.

The levels of details for input data for the inventory database were discussed in Section 8. The extent of data in the database of unit factors is proportional to the content of the inventory database.

With reference to the level of detail in the cost estimation, the extent of details in the ISDC cost calculation structure should be adjusted. How to develop and grade the ISDC cost calculation structure was discussed in Section 9.1.3.

Both approaches to grading the level of detail in the input data and the level of detail in the ISDC cost calculation structure are presented in Fig. 10. Grading of the input data and the extent of calculation is presented in the context of the development of the decommissioning plan, the evolution of the decommissioning strategy and the planning of the individual stages of decommissioning.

A summary of grading in relation to discussions in the previous sections is given in the following paragraphs.

9.6.1. Costing at the preliminary level

A basic set of input data is sufficient. As an example, approximately 10–15 categories of equipment, surfaces and building materials could be enough. The ISDC level for this stage could be 'ISDC 100' for period dependent activities and 'ISDC 1000' for hands-on activities. Typical for this stage are robust cost estimates. The inventories are developed mostly as the estimates of experts and the basic set of techniques and unit factors relevant for the content of the inventory database and relatively simple waste management schemes. Typical content of data in the databases is in the range 10^2–10^3 items.

9.6.2. Costing at the conceptual level

Typical for this level is the periodic upgrading of the decommissioning plan in several stages with increasing levels of detail. A medium level of decommissioning categories is typical, ranging to approximately 20–50 categories of equipment, surfaces and building materials. The ISDC level of the standardized cost calculation structures ranges typically to 'ISDC 1000' for period dependent costs up to approximately 'ISDC 1000.xx.xx' for hands-on activities. For the development of input data contained in the inventory database and the database of unit factors, activities such as the review of documents, in situ inspections, intermediate techniques and unit factors are typical. Conceptual modelling in developing the radiological data and conceptual waste management schemes are typical. During the cost estimation stages, the concept of multiple decommissioning options is retained with the final selection of an optimum decommissioning option. The typical content of data in the databases is in the range 10^3–10^4 items.

9.6.3. Detailed cost estimation

At this level, normally only one (optimum) decommissioning option is under consideration. The level of detail in the inventory database equates to approximately hundreds of decommissioning categories. Relevant supporting data in the database of unit factors are also required. The level of detail in the standardized cost calculation structure ranges from 'ISDC 1000.xx.xx' for the period dependent activities up to 'ISDC 1000.xx.xx.xx' and more for hands-on activities. Methods used for detailed inventories include sophisticated computer modelling (especially for the estimation of activation of reactor components and of materials of the biological shield), detailed techniques and unit factors and detailed waste management schemes. The typical content of data in the databases normally exceeds 10^4 items. The data developed for the final decommissioning plan can be further improved during the development of detailed plans for executing the decommissioning activities. This is the normal procedure for a power reactor and, in principle, can also be adopted for research reactors. Since the facilities defined for this publication are small and medium facilities, the final decommissioning plan can also be used as the plan for performing decommissioning activities.

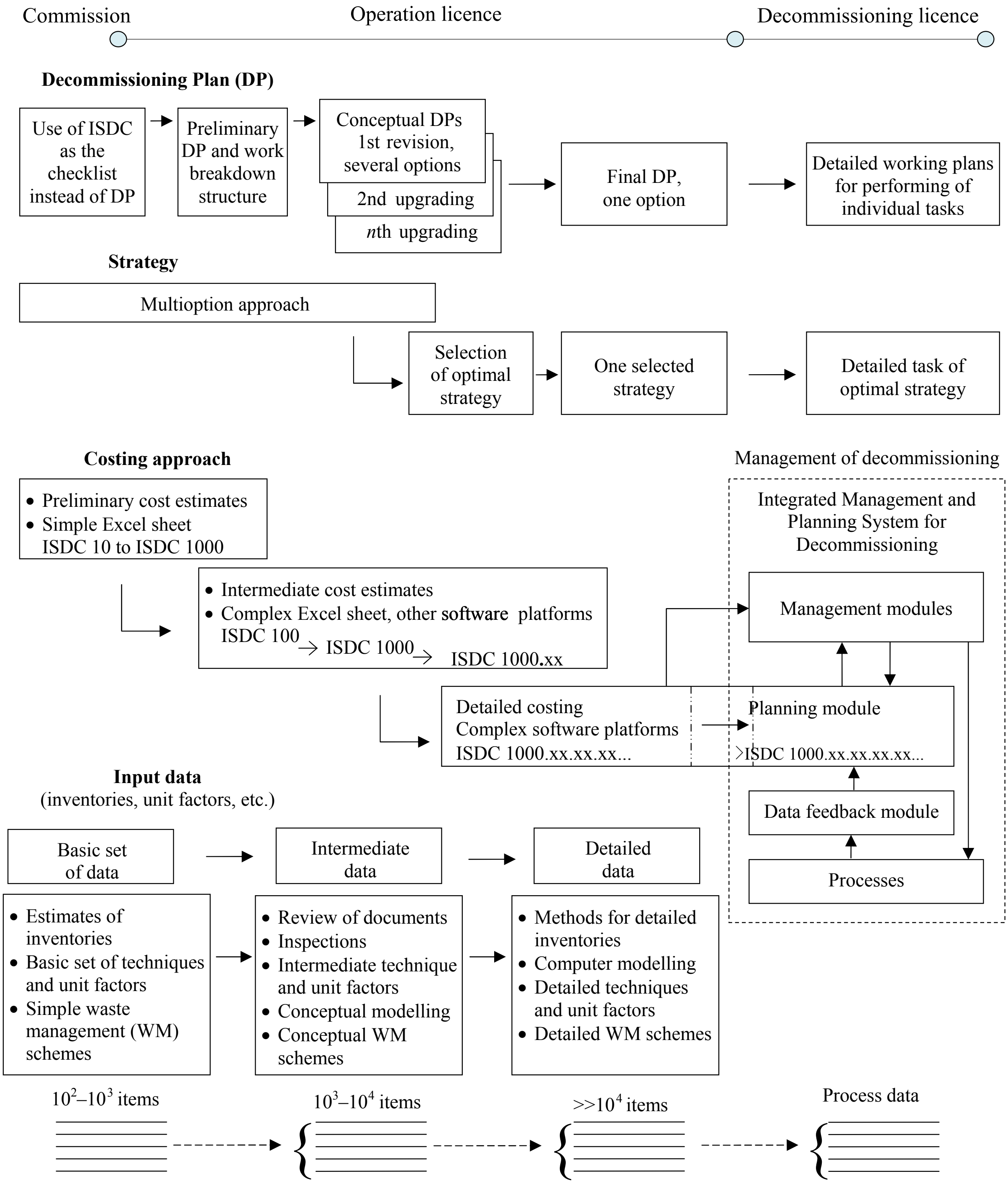

FIG. 10. Principal scheme for grading in decommissioning costing.

10. IMPLEMENTATION OF ISDC COSTING IN THE COSTING MODEL FOR RESEARCH REACTORS

10.1. BACKGROUND FOR THE COSTING MODEL FOR RESEARCH REACTORS

This section presents the proposed approach for the costing model for research reactors based on current experience in decommissioning costing and based on the requirement to develop a robust cost estimation model for research reactors. The ISDC is the basis for the costing approach; this is in line with promotion of the ISDC for decommissioning costing.

Research reactors, for the purpose of this publication, are considered as being small and medium facilities with a thermal power rating at the megawatt level. The demarcation line assumed for application here is approximately at a power level of several megawatts. Research reactors with a power level of tens of megawatts or more (some have a power output of hundreds of megawatts) have complex systems and structures comparable with power reactors. For the decommissioning of these nuclear facilities, the procedures, techniques, processes, planning, management and support for the decommissioning of power reactors are more suitable.

The costing model for research reactors is intended for the preliminary costing stages as a first estimation of the magnitude of the costs of decommissioning. It is expected that a limited extent of input data is available at this stage. Design documentation and operational documentation will be the main sources of inventory data. Missing inventory data will be developed as estimates.

The users of the costing model will mostly be the operators of research reactors. It is expected that these operational personnel knew the facility during its operational period and will be able to estimate the input data for period dependent activities and collateral costs by the estimation of data from operations. The expected knowledge of the costing process by these personnel is limited; hence, the approaches presented in this publication may be the basis for obtaining decommissioning costs.

It is also expected that decommissioning plans will not be available at the time of this preliminary costing stage; only the intended decommissioning strategy will be available. Under these conditions, the use of the ISDC facilitates the preliminary costing; the use of the ISDC as a checklist for decommissioning activities takes over the role of the decommissioning plan for a decommissioning project. Hence, the ISDC, as the basis for the cost calculation structure, seems to be the appropriate solution.

On the basis of the assumptions listed above, the costing model for research reactors should be able to be operated with a limited extent of input data and with limited or basic costing experience by the users.

10.1.1. Current aspects of costing for research reactors

One of the main messages for future activities in decommissioning costing, as presented in Ref. [10], is that it is increasingly important to ensure that greater cost effectiveness should be achieved in the management of nuclear liabilities, including research reactors. Possible ways to achieve this are to identify less capital intensive, simpler technological options. It should be possible to save money within a given framework of objectives by exploring the deficiencies of the current strategies. The future trend is to achieve a better understanding of decommissioning cost estimates and, based on those, to fine tune the funding mechanisms.

The cost estimating process models the decommissioning process. A better understanding of the costing process, a clear definition and mutual links of the individual costing elements should reflect all relevant aspects of the decommissioning process and could enhance the modelling in order to be closer to the real process. In this way, the decommissioning costing will also be able to optimize the decommissioning processes in order to define the optimum cost and time structure, and to ensure the safety of the process.

Cost estimates are essential to secure an appropriate level of funding for a decommissioning programme. Therefore, the IAEA recommends that a decommissioning cost study be carried out early in the life cycle of a facility and that the first draft of the decommissioning plan be drawn up during construction. This plan should be updated regularly and finalized prior to implementation of the decommissioning strategy. These recommendations have not yet been fully implemented in a number of countries, but a positive trend is emerging.

One of the main features of decommissioning cost estimating for research reactors is the fact that individual cost estimates are based on national or the owner's experience, and the estimates are very different to the structures, the methodologies implemented and the formats of the estimated data. The costing methods applied range from simple estimation based on estimated workforce for individual tasks up to dedicated sophisticated software. This general feature can also be identified in decommissioning costing for power reactors.

Much effort has been expended by international organizations involved in decommissioning (EC, IAEA, OECD/NEA), in order to implement harmonization in decommissioning costs. The most important result was the proposal for the standardized structure of cost items for costing purposes [3, 4]. Experience with this structure has shown that this is practically the only way to overcome differences in estimation and present the costs of decommissioning and to achieve consistency among decommissioning projects [13]. The standardized structure of cost items, as a list of decommissioning activities, could effectively support harmonization in decommissioning costing when this list is used as the common platform for the cost calculation structure.

There is a trend towards using comprehensive parametric cost estimation models [10] supported by extensive databases. However, research reactors are so varied that each case is best approached by taking into account site specific factors. New approaches are expected to contribute to the accuracy of future cost estimates by using benchmarking based on cumulative experience. Robust estimates, quantified within defined levels of certainty, can be achieved through the use of techniques such as quantity surveys, multipoint estimating, experience from previous decommissioning projects and risk analysis.

However, general experience in estimating should be adapted to the area of decommissioning owing to significant specific features of the decommissioning process [10]. Some difficulties are expected in the circulation of results because of commercially sensitive information.

10.1.2. Requirements for costing of research reactors

In general, there are many issues that impact on decommissioning costs, so an effective decommissioning costing methodology should consider those variables with a major impact on decommissioning costs. The main cost drivers for decommissioning are the following:

- The extent of decommissioning activities involved in the decommissioning project (inventory of decommissioning activities);
- The type, size, physical and radiological properties of the facility (systems and structure inventory and related radiological data);
- The techniques and processes implemented for individual activities (dismantling, decontamination, demolition, waste treatment, disposal, release, legislative aspects, etc.);
- The personnel involved in decommissioning activities for preparation of decommissioning, management, support activities, surveillance, maintenance and similar activities;
- The list of collateral costs related to the decommissioning case.

The inventory of decommissioning activities for types and extent of groups of individual activities is defined mainly by the decommissioning strategy, end state, national legislation framework for decommissioning and applicable decommissioning infrastructure. The extent of decommissioning activities should be developed and/or adapted as project specific activities. The extent of decommissioning activities for a given decommissioning case, taking into account the above listed aspects, is defined in the decommissioning plan. The decommissioning plan, covering all decommissioning activities specific to the decommissioning case, is the ultimate requirement for effective decommissioning costing. At the level of preliminary costing, other structures and/or systems should be available that define the inventory of decommissioning activities for a given decommissioning case. The ISDC, as the structure defining all types of decommissioning activity, is capable of replacing the decommissioning plan at the preliminary costing stages.

The type, size, construction materials and physical and radiological properties of the facility define the extent and type of techniques applicable for utilization during decommissioning of the facility.

Techniques implemented in the project should be simple and industrially proven techniques or sophisticated systems developed and/or adapted for specialized purposes. The costs of procurement, development, maintenance and application in decommissioning may vary to a large extent. Waste management includes treatment of typical waste forms and final solutions for disposal or the release of materials or site. In some cases, long term storage is the intermediate solution. At the preliminary costing stages, the waste management system may refer to main types of waste, e.g. as defined in ISDC Principal Activities 05 at level 2.

The personnel requirements for performing the decommissioning activities vary from simple skills with very basic training, through to specialized skilled workers, up to university graduate level, depending on the complexity of the decommissioning project, the techniques implemented, the extent of research and development or any specialized decommissioning activities required.

Identification of personnel for non-operational activities, such as for management, technical support, maintenance, surveillance and operation of auxiliary systems, is the prerequisite for effective costing. The ISDC model enables the incorporation of activities of this type together with time phasing for a decommissioning project. A list of collateral costs as the list of items to be procured, payments, tax, insurance and other financial items should be developed for the decommissioning project under evaluation.

In addition to the above aspects of decommissioning, the safety of personnel, the public and the environment is a key requirement for decommissioning. These aspects are highlighted in EC, IAEA and OECD/NEA publications related to decommissioning. The safety of the processes should be preserved at each decommissioning step within the defined limits for personnel and the public. Compliance with applicable safety standards imposes additional costs that require consideration.

The proposed costing model should be able to consider all the basic requirements listed above, and should be harmonized into the standardized cost structure [4]. The parametric cost estimation system as presented in Ref. [10] can be used only for an indication of decommissioning costs under the condition that a similar costing case already exists. The ratios between the main cost drivers and total costs should also be available. The ISDC costing model, as presented in this publication, should be capable of developing cost estimates independently of other costing methods.

Another aspect of decommissioning costing, as highlighted especially in Ref. [8], is that the decision making process should be based on the evaluation of a set of decommissioning options that covers the extent of decommissioning scenarios applicable for the given facility and decommissioning and waste management infrastructures. This approach should be applied up to the stage of final selection of the optimum decommissioning scenario. The ISDC costing model for research reactors may be implemented in two or more costing cases where there is a requirement to evaluate several decommissioning strategies at the level of the preliminary costing stage.

10.1.3. Summary of ISDC costing and relation to costing model for research reactors

The costing methodology for research reactors should cover all aspects from collection of the data required for costing, through development of the calculation case, its calculation and optimization, up to final formatting of the calculated data. On the basis of the information presented in Sections 6–9 related to general costing aspects and to the ISDC, a summary of ISDC costing in relation to research reactors is as follows:

- Types of research reactor to be covered by the costing model;
- General approach in the costing methodology for research reactors;
- Implementation of the ISDC;
- Costing methodology;
- Input data for the costing model;
- Software for the costing of research reactors.

10.1.3.1. Types of research reactor to be covered by the costing model

The classification of research reactors is presented in Ref. [6] and in Section 5. The ISDC structure covers all typical decommissioning activities. Typical structures for decommissioning activities for individual types of research reactor, as identified in decommissioning projects, may be transformed into ISDC format. In principle, decommissioning activities for any type of research reactor are covered by the ISDC. There is a great deal of information on decommissioning of various research reactors available (e.g. as in Ref. [18]), which may be used for developing costing cases for various types of research reactor. The correct allocation of ISDC numbers for decommissioning activities already analysed is important in order to apply data collected from other decommissioning projects to research reactors.

10.1.3.2. General approach in the costing methodology for research reactors: ISDC implementation

The proposed costing methodology for research reactors is the implementation of the ISDC as the cost calculation structure as the basis of the harmonized cost calculations and the implementation of the general international experience in decommissioning costing (Section 6). The ISDC in its generic definition will be used as the template for the cost calculation structure. Additional calculation segments should be available for extending the ISDC template when required. In this way, the bottom-up approach will be implemented. The individual steps for performing practical decommissioning costing include the development of the input data for the facility (inventory database and database of unit factors), adaptation of the ISDC cost calculation structure for the costing case, calculation of the data, optimization of the calculation case and formatting the calculated data in ISDC format. For grading of the approach to costing, the first approach presented in Fig. 10 is selected. The ISDC is used as the checklist for decommissioning activities. The decommissioning plan and the WBS of the decommissioning project need not be available at this stage. Calculated data will be formatted in ISDC format.

10.1.3.3. Costing methodology

The proposed calculation methodology implements the basic cost categories: hands-on activities, period dependent activities, collateral costs and adjustment of total cost by contingencies, as presented in Section 6. The level of detail in the cost calculation should be adjusted to the level of detail in the input data (inventory data, unit factors, etc.). A limited extent of decommissioning categories (Section 9.3) should be used that covers all types of components of systems and structures identified in any type of research reactor. This approach is the implementation of the unit factors approach. Waste types should be limited to those defined at the second ISDC level in order that the waste system corresponds to the level of the preliminary costing level. The level of detail for period dependent activities and for collateral costs is recommended to be at ISDC level 2; in some simple cases, also at level 1. Level 3 may be used when more detailed data are available.

10.1.3.4. Input data for the costing model

Input data for the costing model will be organized according to the information presented in Section 8 as the inventory data, unit factors and other data for decommissioning categories (decommissioning activities and waste management activities), data for waste inventories (decommissioning waste and historical/legacy waste) and data specific for period dependent activities and collateral costs. The structure of inventory data and data for waste items will be organized in formats compatible with the ISDC calculation items.

10.1.3.5. Software for the costing model for research reactors

The costing model should be developed in software that is generally available and easy to use without any additional training. Excel software meets these requirements. The structure of Excel spreadsheets enables the easy definition of the calculation case and the easy introduction of the inventory data, unit factors and other input data for the calculation.

10.2. IMPLEMENTATION OF ISDC COSTING INTO THE COSTING MODEL FOR RESEARCH REACTORS

10.2.1. The ISDC costing model for research reactors and the review scheme

10.2.1.1. General background of the costing model

The costing model for research reactors is intended for preliminary cost estimates with a limited extent of inventory data and limited costing experience by the users. At this costing stage, only the intended decommissioning strategy is generally known. The decommissioning plan and related WBS for the given decommissioning project are not available. The role of the decommissioning plan is taken over by the ISDC and used as the checklist for decommissioning activities. Decommissioning activities identified in the ISDC checklist, as relevant for the costing case, may be introduced into the costing case at the various ISDC numbered levels and, when required, the same ISDC activities may be repeated in the costing model. Identification of ISDC decommissioning activities for the costing case should be in line with the intended decommissioning costing case.

The main reason for implementation of the ISDC as the checklist is the requirement of the IAEA to promote the ISDC as the platform for harmonization in decommissioning costing models for research reactors. This approach is also in line with the grading for decommissioning costing. Using the ISDC as the checklist also covers waste management activities and spent fuel issues.

On the basis of the proposed characteristics of the costing model for research reactors, as presented in Section 10.1.3, the principal structure of the costing model for research reactors involves the following segments:

- The ISDC cost calculation structure is the key module that implements the ISDC structure and is the prerequisite for harmonization in costing. The ISDC cost calculation structure is linked to the facility inventory database in such a way that the inventory data relevant for individual ISDC numbered items should be able to be allocated.
- The facility inventory database that contains the data of all the systems and structures required for the calculation of costs and workforce.
- Definition of quantities and types of decommissioning waste based on the user's defined partitioning of items in the inventory database. Historical and legacy waste items are defined separately from decommissioning waste items.
- Unit factors for decommissioning techniques and waste management processes, personnel data and other data required as common data for the calculation of cost and workforce.
- Segments for introducing the item specific data (local calculation data) defined by the users as input data specific for individual calculation items — input data for period dependent activities and for collateral costs and the definition of contingency.
- Modules for the processing of calculated data in order to generate the data in ISDC format and to generate the costs and workforce data of the option for presentation.

10.2.1.2. Scheme of the costing model

In principle, the costing model for research reactors is the same as that presented in Fig. 10. Differences arise from the absence of the decommissioning plan and the WBS. The decommissioning plan is replaced by the decommissioning strategy, and the WBS is not required at this stage because the detailed cost profile per year is not required at this stage of costing. The principal scheme of the costing model for research reactors is presented in Fig. 11.

The cost calculation approach is based on information presented in Section 9. Workforce is calculated in the first step and is the basis for the calculation of labour costs. Labour unit cost factors are defined for each skill considered in the costing model. Investment cost items and expense items are calculated based on unit cost factors defined for each decommissioning category and waste management process. Contingency is defined individually for each calculation item as one percentage figure.

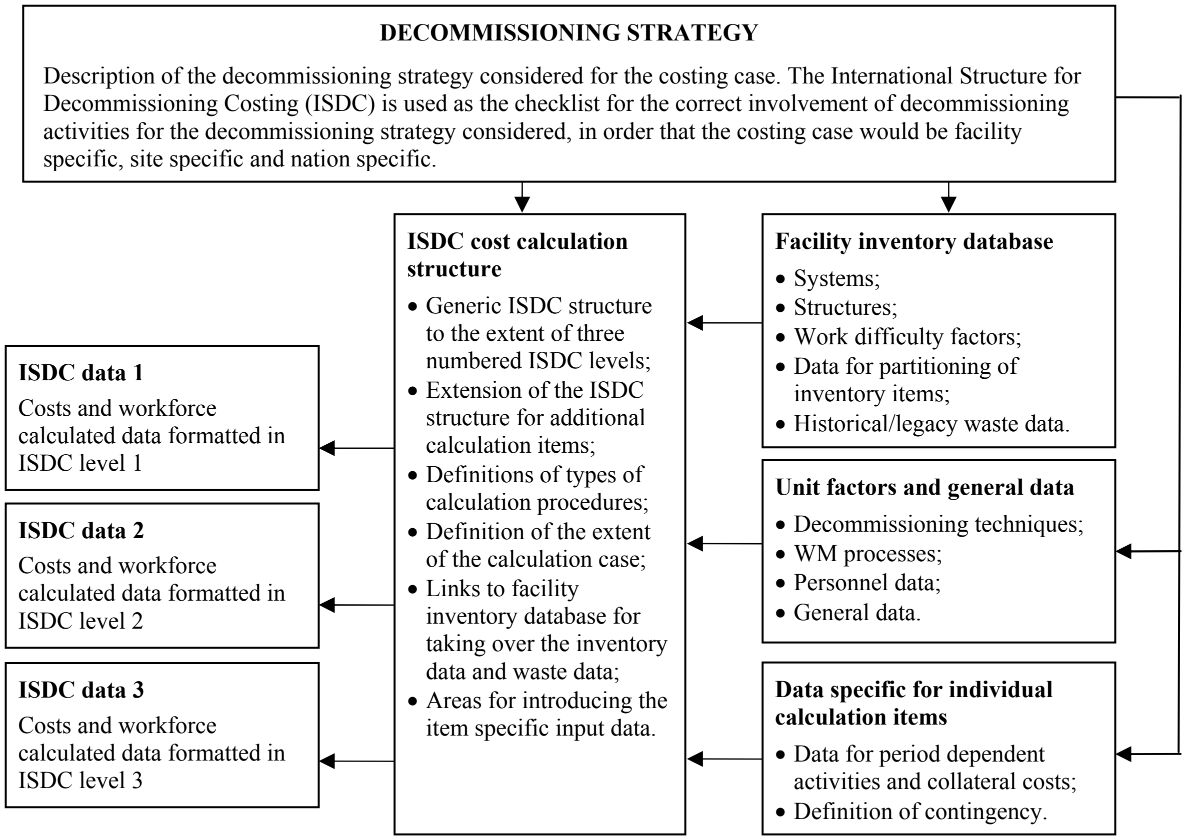

FIG. 11. Principal scheme of the costing model for research reactors.

The ISDC cost calculation structure is the one to one transformation of the generic ISDC as three numbered levels, extended by segments where the users may add additional ISDC calculation items. The transformed ISDC definitions are extended by segments for communication with the facility inventory database and by segments for introducing the item specific input data. Unit factors for decommissioning techniques and waste management techniques and general data are also located here.

The facility inventory database, together with the definition of historical and legacy waste data, is another module of the costing model. The reason for this structure is the approach to calculation of the workforce; work difficulty factors for individual inventory items may be implemented here. The ISDC numbers index inventory items, so the calculated workforce may be selectively taken over to the ISDC cost calculation structure as the basis for calculation of the costs. Quantities of decommissioning waste are derived from the facility inventory data based on partitioning of each inventory item according to the types of waste in the waste management system. Quantities of historical and legacy waste are introduced here individually.

10.2.1.3. Costing methodology

The costing methodology implanted in the costing model for research reactors is based on the principles of the ISDC costing methodology presented in Section 9.2 and in Appendix II. The methodology implements both basic recommended approaches:

— The bottom-up principle, where the calculation is performed at the level of individual elementary decommissioning activities, which are represented by ISDC numbered levels in the costing model;
— The unit factors approach, which is used for inventory dependent activities (decommissioning techniques) and for waste management activities.

Individual elementary calculation items are defined as the items for inventory dependent activities, waste management activities and period dependent and collateral costs. The specifics of the ISDC costing methodology are implemented, i.e. the calculation of workforce resolved by the individual staff skills involved and the separate calculation of investment costs, expenses and contingency. Overheads (Section 9.2.3) are calculated as percentages of labour unit cost factors. The principles of the costing methodology, simplified for preliminary cost estimates for research reactors, are as follows (see Fig. 12):

- Labour cost is calculated based on workforce items and labour unit cost factors. Labour unit cost factors include payments to personnel involved in ISDC items, payments to funds (social security, insurance, charges, etc.); overheads are not included in labour cost because all personnel involved are included in the costing model.
- The calculation of overheads (indirect costs) is calculated in parallel to the calculation of labour costs and is calculated based on the workforce elements and overheads ratio (%) related to labour unit cost factors.
- The calculation of process costs in one step (quantities are not calculated) for inventory dependent activities and for ISDC waste management activities based on inventories, waste volumes and unit factors for investment costs and for expenses. Work difficulty factors are considered in the case of inventory dependent activities.
- The calculation of costs for period dependent activities based on the duration of activities and the composition of working groups defined by users. Period dependent, specific unit cost factors and one-off cost items may additionally be defined by the user for period dependent activities.
- Collateral costs, such as period dependent specific unit cost factors, durations and one-off cost items for procurement, various payments, tax, insurance, income, etc., are defined by the users.
- Contingency is calculated in one step as a percentage related to the sum of labour costs, investment and expenses at the level of each elementary ISDC calculation item. A percentage for contingency is defined individually at the level of the elementary calculation items.

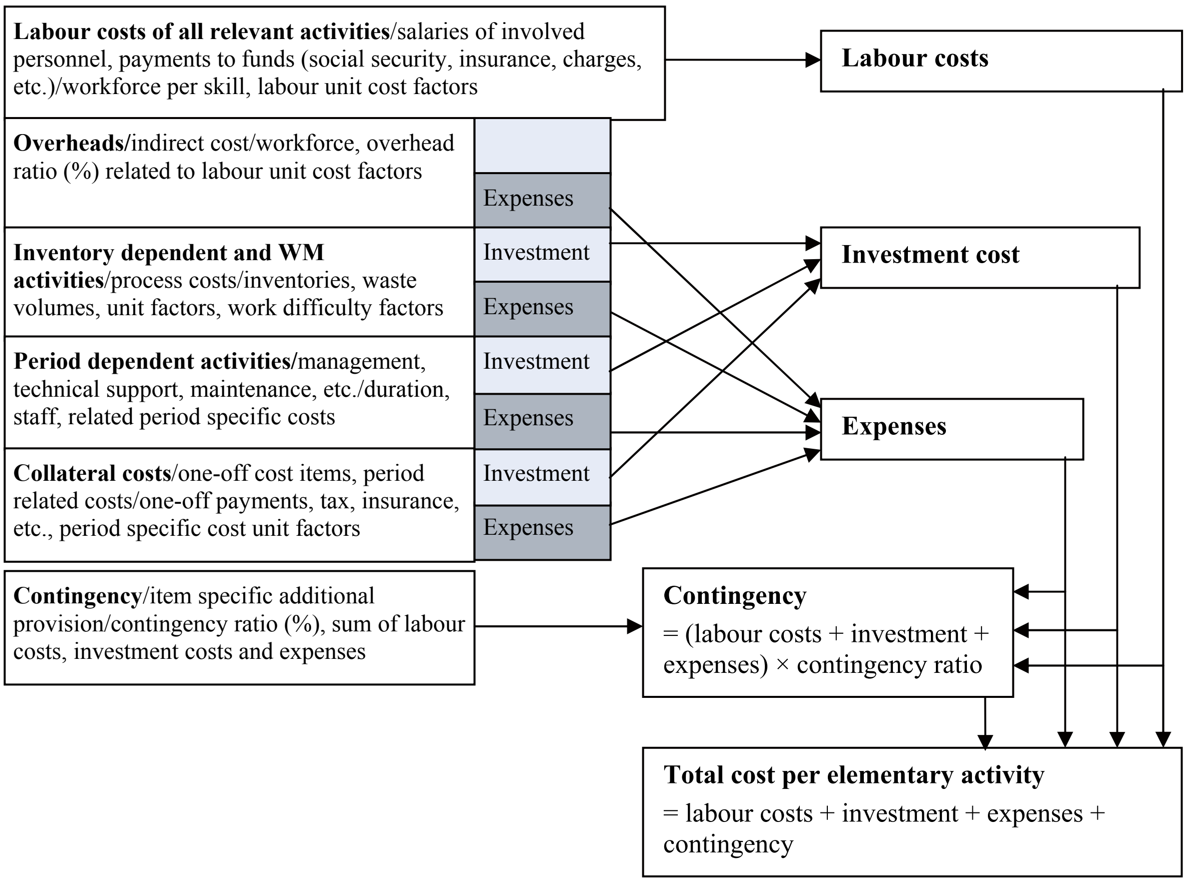

FIG. 12. Principles of the costing methodology implemented in the costing model for research reactors.

There are three parts in the definition of individual items in Fig. 12 that are separated by a forward slash (/). The first part is the definition of the item, the second is the meaning of the item and the third presents the main sources of input data for calculation. The ISDC cost calculation structure also enables the combination of calculations, e.g. inventory dependent activities may be combined with period dependent activities.

10.2.1.4. Software and modules of costing model

The costing model is implemented in Excel software with six spreadsheets as follows:

(i) The 'ISDC' spreadsheet involves the ISDC cost calculation structure, unit factors and general data and data specific for individual calculation items.
(ii) The 'Inventory' spreadsheet involves facility inventory data, work difficulty factors for calculation of workforce for individual inventory items, partitioning data for the definition of the quantities of decommissioning waste and data on historical and legacy waste.
(iii) The 'ISDC Cost Table level 3' spreadsheet presents the cost and workforce at ISDC level 3.
(iv) The 'ISDC Cost Table level 2' spreadsheet presents the cost and workforce at ISDC level 2.
(v) The 'ISDC Cost Table level 1' spreadsheet presents the cost and workforce at ISDC level 1.
(vi) The 'Procedures' spreadsheet where the categories for decommissioning activities, waste management activities and historical and legacy waste are listed as a summary.

The spreadsheets are linked to form one compact calculation structure.

10.2.2. The ISDC cost calculation structure

The ISDC cost calculation structure was developed by direct implementation of the ISDC numbered levels into Excel as a matrix structure involving the three numbered ISDC levels in the vertical direction and extended specific segments in the horizontal direction to create a compact cost calculation structure. Each line in this matrix represents one ISDC item, as defined in the ISDC hierarchical structure. The segments in the horizontal direction are the following (see Fig. 13):

— **The ISDC definition of calculation items** — ISDC numbers, name of the ISDC items and selection of the ISDC item into the specific costing case, definition of the type of calculation procedure — inventory dependent, waste management procedure, period dependent and collateral costs.
— **Calculation segment** for workforce, total costs and ISDC cost categories — labour costs, investment costs, expenses and contingency.
— **Segment for input data for period dependent costs and collateral costs** — duration of the activity, definition of staff, period specific cost factors and one-off costs items. Labour unit cost factors for individual staff skills are defined here, and overheads for the facility owner, the decommissioning licensee and the contractor.
— **Segment for decommissioning categories** — definition of unit factors for workforce and unit cost factors for investment costs and expenses, display of the inventory data for individual ISDC items as the input data.
— **Segment for waste management activities** — definition of capacities for individual waste management activities according to the basic types of radioactive waste, as defined in Ref. [16], unit cost factors for investment costs and for expenses, display of the waste quantities for individual ISDC items. In the case of waste arising from dismantling and demolition out of the controlled area, several sub-items were defined.
— **Segment for historical/legacy waste** — definition of workforce unit factors and unit cost factors for investment costs and for expenses for retrieval of these waste types, displaying the waste data for individual ISDC items.

The costing case is defined by the user's delineation of ISDC items involved in the costing case. The procedure is similar to that presented in Section 9.1.3 and is transformed into a template for the cost calculation structure to be adapted by the users to a specific costing case. Each line may be the subject of calculation, i.e. it is possible to calculate the cost data at any hierarchical ISDC level. In order to exclude conflicts in calculation, if the

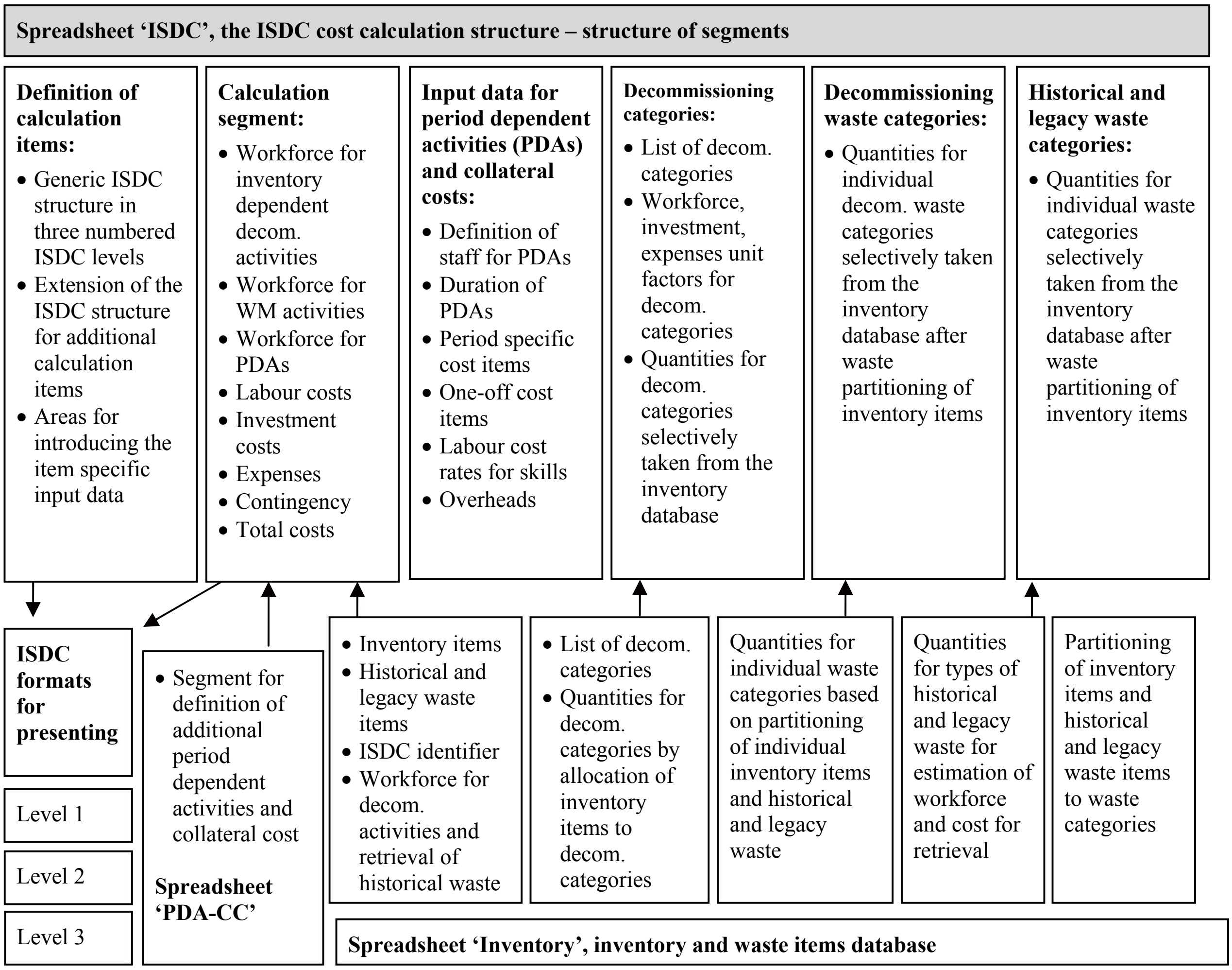

FIG. 13. Principal segments of the ISDC cost calculation structure spreadsheet and main data links to other spreadsheets; content of the spreadsheet for the inventory database and historical/legacy waste; content of the spreadsheets for 'ISDC' presentation formats.

calculation item at a higher level is included into the cost calculation case, the lower levels are excluded from the case; if the data are calculated, they remain latent and will not enter the total cost for the costing case.

Each ISDC calculation item may be used as the item for the calculation of costs of inventory dependent, waste management activities, and of period dependent costs and collateral costs. The basic set for each ISDC calculation item is for period dependent activities and collateral costs. There is a specific segment in which the user may define the calculation to be the item for inventory dependent costs or for waste management activities. Additionally, selected activities may be defined as activities to be performed by the contractor. Different labour cost ratios may be defined by the users.

The calculation of workforce, total cost and ISDC cost categories is performed in the calculation segment equally for all ISDC calculation items. Details of the calculations are presented in Sections 10.2.3–10.2.5. Calculated ISDC cost categories are labour costs, investment costs, expenses and contingency, which is defined by the users in a separate column as the percentage of the sum of labour costs, investment and expenses.

Input data for period dependent activities and for collateral costs are introduced in the segment for data specific for individual calculation items. The duration of activities is introduced here as well as the composition of staff skills for individual period dependent activities. Period dependent specific input data and one-off costs are introduced here.

The segment for decommissioning categories is accessible by the user only for the definition of unit factors for workforce and unit cost factors for investment costs and expenses. Quantities for individual decommissioning categories, displayed in individual ISDC calculation items (defined by the users as the items for calculation of inventory dependent activities), are used for the calculation of investment costs and expenses based on the quantities of decommissioning categories and the relevant unit cost factors. Quantities for individual categories are collected from the inventory database selectively, according to the ISDC numbers.

The segment for waste management activities is accessible by the user only for the definition of unit factors for workforce and unit cost factors for investment costs and expenses. Quantities for individual waste categories, displayed in individual ISDC calculation items (defined by the users as the items for calculation of waste management activities), are used for the calculation of investment costs and expenses based on the quantities of waste type categories and the relevant unit cost factors. Quantities for individual waste categories are collected from the inventory database selectively, according to the ISDC numbers. Both decommissioning waste items and historical and legacy waste items are calculated here.

The segment for historical and legacy waste is accessible by the user only for the definition of unit factors for workforce and unit cost factors for investment costs and expenses for retrieval activities additional to processing of the historical and legacy waste according to the waste types defined in the segment for waste management activities. Quantities for individual waste categories, displayed in individual ISDC calculation items (defined by the users as the items for calculation of waste management activities), are used for calculation of investment costs and expenses based on the quantities of waste type categories and relevant unit cost factors. Quantities for individual waste categories are collected from the inventory database selectively, according to the ISDC numbers.

10.2.3. Costing for inventory dependent activities

Costing for inventory dependent activities (hands-on activities) is performed for each inventory item defined in the inventory database based on the procedure presented in Section 9.3 and modified for the costing model presented in Section 10.2.1. The costing for inventory dependent activities is based on the decommissioning categories, the unit factors for decommissioning categories and the work difficulty factors. The extent of decommissioning categories was selected to cover all typical types of equipment component, structure, surface and demolition material category. The extent should be kept minimal at the preliminary costing stage. Costing for inventory dependent activities is simplified by using one averaged skill for all decommissioning categories. The costing procedure includes the following steps:

- Calculation of basic workforce under ideal working conditions based on the quantity of input variable and the workforce unit factor for the given decommissioning category.
- Multiplication of the basic workforce by work difficulty factors reflecting the working constraints specific for the inventory item. Types of work difficulty factor are presented in the costing model manual.
- Labour cost is calculated based on workforce and the labour unit cost factor for the averaged skill.
- Overheads are calculated based on the workforce and a percentage of the labour unit cost factor; costs are added to the expenses.
- Investment and expenses are calculated in one single step for each cost item as the product of relevant unit cost factors and the quantity of the given decommissioning category (a two step procedure as presented in Appendix II).
- Contingency is calculated in one step using a single percentage contingency ratio.

Inventory items are introduced into the 'Inventory' spreadsheet. Calculation of workforce is performed in the 'Inventory' spreadsheet with the calculation of cost categories in the 'ISDC' spreadsheet. Workforce data and quantities of individual decommissioning categories are carried over from the 'Inventory' spreadsheet to the 'ISDC' spreadsheet to calculate the cost categories.

The following decommissioning categories are available in the costing model:

- Removal of operational solid and liquid waste, sludge, resigns, materials and redundant equipment, etc., from the control area. No waste treatment.
- Decontamination of closed systems using autonomous closed circuits, data for one averaged autonomous circuit.
- Manual decontamination of external surfaces of systems and surfaces of buildings by wipes, foams, gels, acids and other reagents.

— Mechanical/thermal decontamination of building surfaces, high pressure cleaning with water with or without abrasives, nitrogen, carbon dioxide, vacuum cleaning, lasers and others.
— Preparatory and finishing activities in individual rooms as the support for dismantling, decontamination of building surfaces and radiological monitoring of buildings.
— Dismantling of general equipment. Primary segmenting into transport containers.
— Dismantling of the main components with wall thickness over approximately 50 mm. Primary segmenting into transport containers.
— Dismantling of piping (small diameter pipes are in thin wall equipment). Primary segmenting into transport containers.
— Dismantling of tanks and heat exchangers. Primary segmenting into transport containers.
— Dismantling of steel linings on walls, floors, overflow trays. Primary segmenting into transport containers.
— Dismantling of ventilation ducts and thin walled equipment (small piping), filters, etc. Primary segmenting into transport containers.
— Dismantling of pumps, motors, general machinery, cranes, lifting devices, carriages. Primary segmenting into transport containers.
— Dismantling of activated reactor internals and/or highly contaminated components using remote techniques. Primary segmenting into shielded transport containers.
— Dismantling of cables and cable trays; primary segmenting into transport containers.
— Dismantling of general switchboards and electrical cabinets (400 V, 6 kV); primary segmenting into transport containers.
— Dismantling of graphite elements, mostly piece elements. Primary segmenting into transport containers.
— Dismantling of pipes embedded in concrete, pipe bushings and lead-throughs. Primary segmenting into transport containers.
— Dismantling of thermal insulation of systems. No asbestos used as material for insulation. Primary segmenting into transport containers.
— Dismantling of asbestos and other hazardous materials, including all safety measures during dismantling. Primary segmenting into transport containers.
— Dismantling of doors, gates, hatches, structural beams, staircases, etc. Primary segmenting into transport containers.
— Dismantling of massive lead shielding, constructed in large blocks. Primary segmenting into transport containers.
— Dismantling of lead shielding, constructed from bricks, plates, etc. Primary segmenting/dismantling into transport containers.
— Dismantling of other types of shielding. Primary segmenting into transport containers.
— Dismantling of general gloveboxes. Primary segmenting into transport containers.
— Dismantling of remaining types of equipment, furniture, etc. Primary segmenting into transport containers.
— Dismantling of massive concrete, biological shields (thicknesses generally over 700 mm). Primary segmenting into transport containers.
— Removal of contaminated structures (owing to leakages) by mechanical techniques.
— Radiological survey of buildings after removal of all radioactivity over release limits.
— Removal of contaminated soil. Primary removal, sorting and putting into transport containers.
— Dismantling of general equipment and structural components out of the controlled area.
— Demolition of massive concrete out of the controlled area.
— Demolition of standard civil materials, such as plain concrete, prefabricated panels, walls made of bricks, etc.
— Final remediation of the site.
— Final radiological site survey.

Additional decommissioning categories may be defined by the user based on the specific decommissioning costing case.

10.2.4. Costing for waste management activities

Costing for waste management activities is based on the approach presented in Section 9.3.5 and shown in Fig. 8. The waste types in the costing model are considered as the waste definitions at level 2 of ISDC Principal Activities 05 (Appendix I). Overall unit factors covering all types of waste management activity defined at the third ISDC level are defined for the waste types at ISDC level 2. Quantities of decommissioning waste are derived from the facility inventory data and based on partitioning of each inventory item according to the types of waste in the waste management system. A direct link is thus created between the inventory data and the waste management system in the costing model.

Quantities of historical and legacy waste are introduced by the users as input data. These quantities are used for the calculation of workforce for retrieval of historical and legacy waste. The procedure for workforce calculation is the same as that for inventory dependent activities, i.e. use of workforce unit factors for individual types of historical and legacy waste and adjustment of the workforce by work difficulty factors defined by the user according to the local conditions for retrieval. After the retrieval, the historical and legacy waste items are processed according to the types of waste defined for waste management.

ISDC items 05.0200 to 05.0600 are assigned for historical/legacy waste and ISDC items 05.0700 to 05.1300 for decommissioning waste. Workforce is calculated as the product of the workforce unit factor and the quantity of given waste type. The labour cost is calculated based on the workforce and labour unit cost factor for the averaged skill; the same approach as that used for inventory dependent activities. Investment and expenses are calculated as products of the relevant unit cost factors and the quantity of a given waste type. No work difficulty factors are considered and all working time components are involved in the workforce unit factor. Contingency is calculated in one single step using one percentage contingency ratio.

A definition for quantities of waste items for processing by partitioning of inventory items and historical/legacy waste items is presented in Fig. 14. Introducing the historical and legacy waste and partitioning of decommissioning waste and historical and legacy waste are performed in the 'Inventory' spreadsheet.

Establishment, operation of auxiliary systems, demobilization and/or decommissioning of the waste management system are included in a specific ISDC item, i.e. 05.0100.

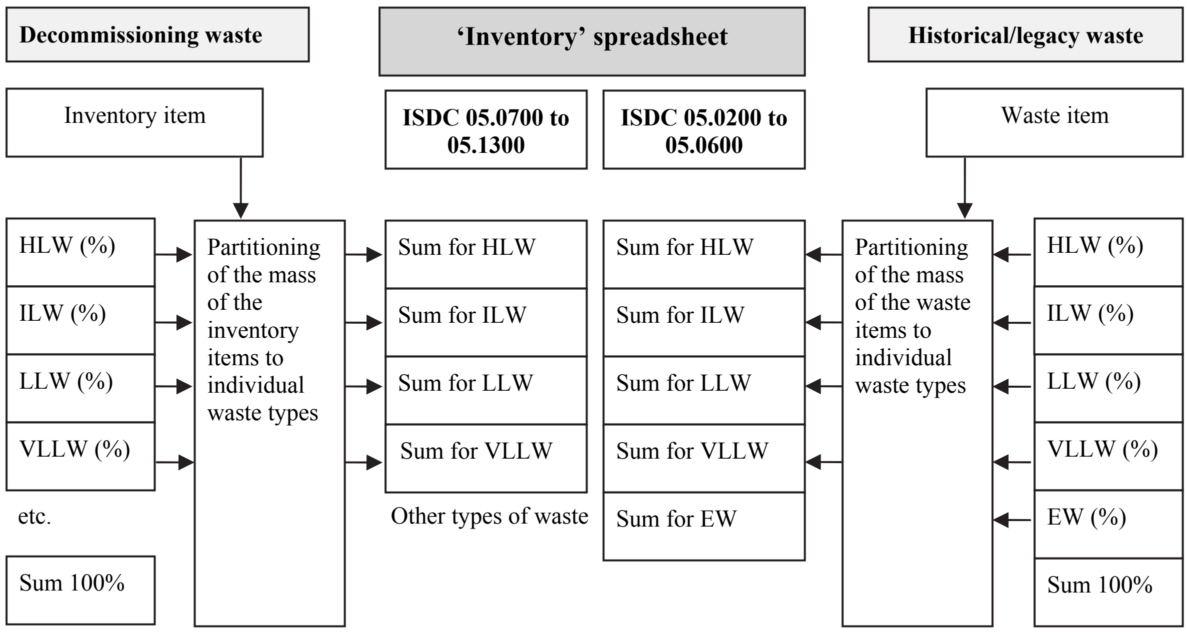

FIG. 14. Principle of definition of waste items for processing by partitioning of inventory items and historical/legacy waste items. EW — exempted waste; HLW — high level waste; ILW — intermediate level waste; LLW — low level waste; VLLW — very low level waste

10.2.5. Costing for period dependent activities and for collateral costs

The following input data should be introduced by the user for the calculation of costs for individual period dependent activities:

— Duration of the elementary decommissioning activity;
— Staff by definition of the number of personnel per individual skill in the working group.

Workforce is calculated as the product of the duration and the number of members of staff. Labour costs are calculated as the sumproduct of labour unit cost factors for individual staff skills and partial workforce items for individual skills of the staff. The following skills are considered in the definition of period dependent activities:

— Auxiliary worker with no specialized training, only general training for work within the controlled area is considered;
— Skilled worker with specialized training;
— Technician with specialized training, secondary school education;
— Administrative worker skilled for administrative office work, secondary school education;
— Graduate engineer, university level;
— Graduate engineer, university level, approximately 10 years of experience in the subject area;
— Managerial level, university graduate, long term experience in the subject area;
— Average level of personnel involved in decommissioning, a weighted average of all the skills in a typical decommissioning project.

If there are period specific costs or one-off costs directly allocated to the period dependent activity, the period specific costs are calculated as the product of the duration of the period dependent activity and the period specific cost factor and allocated to the relevant cost category (investment or expenses). The one-off cost is expressed as one figure for the period dependent activity under evaluation and is transformed to the relevant cost category (investment or expenses). Contingency is calculated in one single step using a single percentage contingency ratio.

10.2.6. Formats for presenting the cost data

Data calculated in the costing model are presented in the ISDC format according to Section 9.5. There are three spreadsheets in the costing model for presenting the cost and workforce:

(i) Level 3 ISDC, with the full list of ISDC items at the third numbered level (typical activities);
(ii) Level 2 ISDC, with the list of ISDC items at the second level (activity groups);
(iii) Level 1 (principal activities).

The spreadsheets are linked to the ISDC spreadsheet containing the ISDC cost calculation structure where the calculated data are available. Calculated data are taken from the calculation items in the ISDC spreadsheet based on ISDC indexing. The content of the ISDC presentation format is as follows:

— Index, indicating the incorporation of the calculation items in the costing case;
— ISDC number;
— Name of the ISDC item;
— Workforce;
— Total costs;
— Labour costs;
— Investment costs;
— Expenses;
— Contingency.

In the ISDC format for level 3, the data are taken from the ISDC spreadsheet at the third level; the second level and the first level are the aggregating levels. Data in spreadsheets for level 2 and level 1 are taken from the spreadsheet for the third ISDC level. No additional user activities are required for presenting the calculated data due to on-line data linking to the cost calculation structure.

10.2.7. Aspects of use of the costing model

The requirement for easy to use software with no additional training requirements is fulfilled by selecting Excel, as stated in Section 10.1.3. A manual is available for using the costing model, enabling the wide use of the Excel costing model. However, it is expected that the costing model will be used by experts who are familiar with the facility to be decommissioned. This aspect seems to be one of the most important because, while the basic knowledge in costing may be obtained using this publication and the costing model manual, knowledge of the facility is vital for estimating the inventory data, waste data and any activities related to the costing case.

There are also many publications available that address decontamination, dismantling and other decommissioning techniques; being familiar with these publications facilitates understanding of the costing process.

10.2.8. Modules in the costing model

The user manual describes the purpose, functionalities and methods of using the CERREX software for preliminary cost estimates of research reactor decommissioning:

- Section 2 gives a review of the costing methodology used.
- Section 3 presents the structure of the software.
- Section 4 presents the procedures for using the software, such as the definition of the facility, definition of the project and summary of the input data.
- Section 5 presents the ISDC spreadsheet and the detailed content of individual calculation cells in Excel and how to extend the cost calculation structure when it is required for a particular costing case.
- Section 6 presents the module Inventory, comprising a general identification of items, inventory of materials, inventory of waste, partitioning coefficients for waste categories, secondary waste generation ratios and use of the work difficulty factors.
- Section 7 presents the ISDC presentation formats.
- Section 8 lists the decommissioning categories and waste types for which the unit factors are developed.
- Section 9 reviews the implementation of the ISDC structure in the CERREX software, the cost calculation structure, the ISDC preliminary costing methodology and the calculation of workforce components, labour costs, investment costs, expenses and contingency. Finally, a summary of the ISDC preliminary costing methodology is given.

10.2.9. Practical steps in using the costing model

According to the instructions in the manual, the main practical steps in using the costing model may be summarized in the following sections.

10.2.9.1. Definition of the costing case

The extent of the costing case is defined in the ISDC spreadsheet by indexing the individual ISDC items to be calculated in the costing case (i.e. the ‘activation’ of the calculation items). Indexing of ISDC items at level 2 excludes the items belonging to the third level. Similarly, indexing the ISDC items at level 1 excludes items belonging to the second and third levels. When additional items are required at the third level, this can be done in the separate spreadsheet PDA-CC.

Types of decommissioning activity and inventory dependent and waste management activities are predefined in the ISDC cost calculation structure. Any items may be used as the item for period dependent activities and collateral costs. Modification of this setting can be carried out by the user, as well as the allocation of contractors when this information is available. Contingency may be defined for each calculation item individually as the percentage of the sum of calculated labour costs, investment costs and expenses.

10.2.9.2. Input data for period dependent costs and collateral costs

Input data are defined in the ISDC spreadsheet as the duration of the elementary activities and the staff required for the activities. It is possible to introduce period specific cost data and one-off cost data, both as the investment costs or as expenses, into each calculation item.

10.2.9.3. Inventory data

Inventory data for the costing case are introduced into the Inventory spreadsheet. The inventory data are indexed by ISDC numbers and allocated to the correct ISDC calculation item. Inventory items without ISDC indexing will not be entered into the calculation. Inventory items to be included in the costing case should be activated by indexing.

Input variables (t, m^2, etc.) for each inventory item are allocated to the relevant decommissioning categories. This is the basis for the calculation of basic workforce as the product of the input variable and the workforce unit factors for individual decommissioning categories. For each inventory item, work difficulty factors are allocated according to the specific conditions related to individual items. This is the basis for the calculation of increased workforce under specific working constraints.

A partitioning scheme is defined for each inventory item using the percentage coefficients relevant for the waste types considered in the waste management system of the costing model. The user, in a separate segment, defines the generation of secondary waste for individual types of waste. This gives rise to the decommissioning waste flow in the costing model.

Several inventory items may be defined for the same ISDC calculation line. Specific working conditions for individual inventory items are evaluated in the Inventory spreadsheet individually by increasing the workforce for individual inventory items. Input variables for identical decommissioning categories are summed, and the process costs related to aggregated quantities are calculated in the ISDC spreadsheet. In this way, the quantity of inventory items is not limited.

It is recommended that those components and structures that differ in decommissioning categories and in specific working constraints be defined as inventory items.

10.2.9.4. Historical and legacy waste

Historical and legacy waste items are introduced into the waste management scheme using the ‘Inventory’ spreadsheet. Waste items are indexed in a similar manner to the inventory items. Waste items are introduced into the segment for the retrieval of historical and legacy waste. The partitioning scheme is defined in an independent segment.

Several historical and legacy waste items may be defined in the same ISDC calculation line, similar to the case of inventory items.

10.2.9.5. Decommissioning categories and waste management types

There is a set of decommissioning categories with unit factors. Additional categories, as required, may be defined by the users in the costing case. Waste types considered are in line with the ISDC definition of Principal Activities 05, level 1. The users may define additional waste types.

10.2.9.6. Data for personnel and general data

Labour unit cost factors for each skill are defined in the ISDC spreadsheet, together with the overheads percentage in relation to labour cost unit factors, for owner, licensee and contractor (one contractor is considered for sake of simplicity). Other general information to be introduced by the user is the number of working days per year.

10.2.9.7. Calculation and presentation of the costing case

The Excel software performs automatic recalculation after each change of setting and change of input data. Calculated results are available.

10.2.9.8. Optimization of the costing case

Costing cases may be optimized by modification of the settings used in the costing case, i.e. by modification of the inventory data, work difficulty factors, unit factors and inventory waste partitioning, and by modification of the period dependent activities, personnel and general data.

11. CONCLUSIONS

This publication presents the principles and background for a costing methodology based on the ISDC and intended for the preliminary costing stages of the decommissioning of research reactors. The methodology presented implements actual experience in decommissioning costing and is in line with IAEA efforts for promoting harmonization in this field.

The ISDC is the platform that involves all typical decommissioning activities in any decommissioning project. Hence, the ISDC may be used as a checklist for decommissioning activities for a decommissioning project at the preliminary costing stages when a decommissioning plan is not yet available. It can also serve as the base for cost calculation structures.

The general ISDC costing methodology as presented here was modified in CERREX into a simpler version suitable for preliminary costing stages using Excel spreadsheets. The methodology is intended for research reactors and other small nuclear facilities.

It is expected that former and current operators of research reactors that are familiar with the facility will use CERREX. A basic knowledge of general decommissioning issues is recommended, such as decommissioning strategies, characterization, dismantling and decontamination techniques, organization and management of decommissioning, management of waste from decommissioning, costing and funding, together with other principal aspects of decommissioning.

Costs and workforce are the parameters calculated in CERREX as being the most representative data for the decommissioning project. The calculated data are presented in ISDC formats at three ISDC numbered levels.

The software tool may be used with limited facility inventory data that are grouped according to the decommissioning categories proposed for costing purposes. The waste management system implemented in CERREX is organized according to the waste types defined by the IAEA [15].

Appendix I

SUMMARY OF ISDC COST ITEM HIERARCHY

01 Pre-decommissioning actions

01.0100 Decommissioning planning

01.0101 Strategic planning
01.0102 Preliminary planning
01.0103 Final planning

01.0200 Facility characterization

01.0201 Detailed facility characterization
01.0202 Hazardous material surveys and analyses
01.0203 Establishing a facility inventory database

01.0300 Safety, security and environmental studies

01.0301 Decommissioning safety analysis
01.0302 Environmental impact assessment
01.0303 Safety, security and emergency planning for site operations

01.0400 Waste management planning

01.0401 Establishing waste management criteria
01.0402 Developing a waste management plan

01.0500 Authorization

01.0501 Licence applications and licence approvals
01.0502 Stakeholder involvement

01.0600 Preparing management group and contracting

01.0601 Management team activities
01.0602 Contracting activities

02 Facility shutdown activities

02.0100 Plant shutdown and inspection

02.0101 Termination of operation, plant stabilization, isolation and inspection
02.0102 Defuelling and transfer of fuel to spent fuel storage
02.0103 Cooling down of spent fuel
02.0104 Management of fuel, fissile and other nuclear material
02.0105 Isolation of power equipment
02.0106 Facility reuse

02.0200 Drainage and drying of systems

02.0201 Drainage and drying of closed systems not in operation
02.0202 Drainage of spent fuel pool and other open systems not in operation
02.0203 Removal of sludge and products from open systems
02.0204 Drainage of special process fluids

02.0300 Decontamination of closed systems for dose reduction

02.0301 Decontamination of process installations using operational procedures
02.0302 Decontamination of process installations using additional procedures

02.0400 Radiological inventory characterization to support detailed planning

02.0401	Radiological inventory characterization
02.0402	Underground water monitoring

02.0500 Removal of system fluids, operational waste and redundant material

02.0501	Removal of combustible material
02.0502	Removal of system fluids (water, oils, etc.)
02.0503	Removal of special process fluids
02.0504	Removal of waste from decontamination
02.0505	Removal of spent resins
02.0506	Removal of specific operational waste from fuel cycle facilities
02.0507	Removal of other waste from facility operations
02.0508	Removal of redundant equipment and materials

03 Additional activities for safe enclosure or entombment

03.0100 Preparation for safe enclosure

03.0101	Decontamination of selected components and areas to facilitate safe enclosure
03.0102	Zoning for long term storage
03.0103	Removal of inventory not suitable for safe enclosure
03.0104	Dismantling and transfer of contaminated equipment and material to containment structure for long term storage
03.0105	Radiological inventory characterization for safe enclosure

03.0200 Site boundary reconfiguration, isolation and securing structures

03.0201	Modification of auxiliary systems
03.0202	Site boundary reconfiguration
03.0203	Construction of temporary enclosures, stores, structural enhancements, etc.
03.0204	Stabilization of radioactive and hazardous waste pending remediation
03.0205	Facility controlled area hardening, isolation for safe enclosure

03.0300 Facility entombment

03.0301	Facility entombment as end state of decommissioning strategy
03.0302	Institutional controls and monitoring of the entombment end state

04 Dismantling activities within the controlled area

04.0100 Procurement of equipment for decontamination and dismantling

04.0101	Procurement of general site dismantling equipment
04.0102	Procurement of equipment for decontamination of personnel and tools
04.0103	Procurement of special tools for dismantling the reactor systems
04.0104	Procurement of special tools for dismantling in fuel cycle facilities
04.0105	Procurement of special tools for dismantling other components or structures

04.0200 Preparations and support for dismantling

04.0201	Reconfiguration of existing services, facilities and site to support dismantling
04.0202	Preparation of infrastructure and logistics for dismantling
04.0203	Ongoing radiological characterization during dismantling

04.0300 Pre-dismantling decontamination

- 04.0301 Drainage of remaining systems
- 04.0302 Removal of sludge and products from remaining systems
- 04.0303 Decontamination of remaining systems
- 04.0304 Decontamination of areas in buildings

04.0400 Removal of materials requiring specific procedures

- 04.0401 Removal of thermal insulation
- 04.0402 Removal of asbestos
- 04.0403 Removal of other hazardous materials

04.0500 Dismantling of main process systems, structures and components

- 04.0501 Dismantling of reactor internals
- 04.0502 Dismantling of reactor vessel and core components
- 04.0503 Dismantling of other primary loop components
- 04.0504 Dismantling of main process systems in fuel cycle facilities
- 04.0505 Dismantling of main process systems in other nuclear facilities
- 04.0506 Dismantling of external thermal/biological shields

04.0600 Dismantling of other systems and components

- 04.0601 Dismantling of auxiliary systems
- 04.0602 Dismantling of remaining components

04.0700 Removal of contamination from building structures

- 04.0701 Removal of embedded elements in buildings
- 04.0702 Removal of contaminated structures
- 04.0703 Decontamination of buildings

04.0800 Removal of contamination from areas outside buildings

- 04.0801 Removal of underground contaminated pipes and structures
- 04.0802 Removal of contaminated soil and other contaminated items

04.0900 Final radioactivity survey for release of buildings

- 04.0901 Final radioactivity survey of buildings
- 04.0902 Declassification of buildings

05 Waste processing, storage and disposal

05.0100 Waste management system

- 05.0101 Establishing the waste management system
- 05.0102 Reconstruction of existing facilities for decommissioning waste management system
- 05.0103 Procurement of additional equipment for management of historical/legacy waste
- 05.0104 Maintenance, surveillance and operational support for waste management system
- 05.0105 Demobilization/decommissioning of waste management system

05.0200 Management of historical/legacy high level waste

- 05.0201 Characterization
- 05.0202 Retrieval and processing
- 05.0203 Final conditioning
- 05.0204 Storage
- 05.0205 Transport
- 05.0206 Disposal
- 05.0207 Containers

05.0300 Management of historical/legacy intermediate level waste

05.0301 Characterization
05.0302 Retrieval and processing
05.0303 Final conditioning
05.0304 Storage
05.0305 Transport
05.0306 Disposal
05.0307 Containers

05.0400 Management of historical/legacy low level waste

05.0401 Characterization
05.0402 Retrieval and treatment
05.0403 Final conditioning
05.0404 Storage
05.0405 Transport
05.0406 Disposal
05.0407 Containers

05.0500 Management of historical/legacy very low level waste

05.0501 Characterization
05.0502 Retrieval, treatment and packaging
05.0503 Transport
05.0504 Disposal

05.0600 Management of historical/legacy exempt waste and materials

05.0601 Retrieval, treatment and packaging
05.0602 Clearance measurement of exempt waste and materials
05.0603 Transport of hazardous waste
05.0604 Disposal of hazardous waste at dedicated waste dumps
05.0605 Transport of conventional waste and materials
05.0606 Disposal of conventional waste at conventional waste dumps

05.0700 Management of decommissioning high level waste

05.0701 Characterization
05.0702 Processing
05.0703 Final conditioning
05.0704 Storage
05.0705 Transport
05.0706 Disposal
05.0707 Containers

05.0800 Management of decommissioning intermediate level waste

05.0801 Characterization
05.0802 Processing
05.0803 Final conditioning
05.0804 Storage
05.0805 Transport
05.0806 Disposal
05.0807 Containers

05.0900 Management of decommissioning low level waste

05.0901 Characterization
05.0902 Processing
05.0903 Final conditioning
05.0904 Storage
05.0905 Transport
05.0906 Disposal
05.0907 Containers

05.1000 Management of decommissioning very low level waste

05.1001 Characterization
05.1002 Treatment and packaging
05.1003 Transport
05.1004 Disposal

05.1100 Management of decommissioning very short lived waste

05.1101 Characterization
05.1102 Treatment, storage, handling and packaging
05.1103 Final management of decommissioning very short lived waste

05.1200 Management of decommissioning exempt waste and materials

05.1201 Treatment and packaging
05.1202 Clearance measurement of exempt waste and materials
05.1203 Transport of hazardous waste
05.1204 Disposal of hazardous waste at dedicated waste dumps
05.1205 Transport of conventional waste and materials
05.1206 Disposal of conventional waste at conventional waste dumps

05.1300 Management of decommissioning waste and materials generated outside controlled areas

05.1301 Recycling of concrete
05.1302 Treatment and packaging of hazardous waste
05.1303 Treatment and recycling of other materials
05.1304 Transport of hazardous waste
05.1305 Disposal of hazardous waste at dedicated waste dumps
05.1306 Transport of conventional waste and materials
05.1307 Disposal of conventional waste at conventional waste dumps

06 Site infrastructure and operation

06.0100 Site security and surveillance

06.0101 Procurement of general security equipment
06.0102 Operation and maintenance of automated access control systems, monitoring systems and alarms
06.0103 Security fencing and protection of remaining entrances against trespassing
06.0104 Deployment of guards/security forces

06.0200 Site operation and maintenance

06.0201 Inspection and maintenance of buildings and systems
06.0202 Site upkeep activities

06.0300 Operation of support systems

06.0301	Electricity supply systems
06.0302	Ventilation systems
06.0303	Heating, steam and lighting systems
06.0304	Water supply systems
06.0305	Sewage/wastewater systems
06.0306	Compressed air/nitrogen systems
06.0307	Other systems

06.0400 Radiation and environmental safety monitoring

06.0401	Procurement and maintenance of equipment for radiation protection and environmental monitoring
06.0402	Radiation protection and monitoring
06.0403	Environmental protection and radiation environmental monitoring

07 Conventional dismantling, demolition and site restoration

07.0100 Procurement of equipment for conventional dismantling and demolition

07.0101	Procurement of equipment for conventional dismantling and demolition

07.0200 Dismantling of systems and building components outside the controlled area

07.0201	Electricity generating system
07.0202	Cooling system components
07.0203	Other auxiliary systems

07.0300 Demolition of buildings and structures

07.0301	Demolition of buildings and structures from the formerly controlled area
07.0302	Demolition of buildings and structures outside the controlled area
07.0303	Dismantling of the stack

07.0400 Final cleanup, landscaping and refurbishment

07.0401	Earthworks, landworks
07.0402	Landscaping and other site finishing activities
07.0403	Refurbishment of buildings

07.0500 Final radioactivity survey of site

07.0501	Final survey
07.0502	Independent verification of the final survey

07.0600 Perpetuity funding/surveillance for limited or restricted release of property

07.0601	Routine maintenance
07.0602	Surveillance and monitoring

08 Project management, engineering and support

08.0100 Mobilization and preparatory work

08.0101	Mobilization of personnel
08.0102	Establishment of general supporting infrastructure for decommissioning project

08.0200 Project management

08.0201 Core management group
08.0202 Project implementation planning, detailed ongoing planning
08.0203 Scheduling and cost control
08.0204 Safety and environmental analysis, ongoing studies
08.0205 Quality assurance and quality surveillance
08.0206 General administration and accounting
08.0207 Public relations and stakeholder involvement

08.0300 Support services

08.0301 Engineering support
08.0302 Information system and computer support
08.0303 Waste management support
08.0304 Decommissioning support including chemistry, decontamination
08.0305 Personnel management and training
08.0306 Documentation and records control
08.0307 Procurement, warehousing and materials handling
08.0308 Housing, office equipment, support services

08.0400 Health and safety

08.0401 Health physics
08.0402 Industrial safety

08.0500 Demobilization

08.0501 Demobilization of project infrastructure for decommissioning
08.0502 Demobilization of personnel

08.0600 Mobilization and preparatory work by contractors (if needed)

08.0601 Mobilization of personnel
08.0602 Establishment of general supporting infrastructure for decommissioning project

08.0700 Project management by contractors (if needed)

08.0701 Core management group
08.0702 Project implementation planning, detailed ongoing planning
08.0703 Scheduling and cost control
08.0704 Safety and environmental analysis, ongoing studies
08.0705 Quality assurance and quality surveillance
08.0706 General administration and accounting
08.0707 Public relations and stakeholder involvement

08.0800 Support services by contractors (if needed)

08.0801 Engineering support
08.0802 Information system and computer support
08.0803 Waste management support
08.0804 Decommissioning support including chemistry, decontamination
08.0805 Personnel management and training
08.0806 Documentation and records control
08.0807 Procurement, warehousing and materials handling
08.0808 Housing, office equipment, support services
08.0900 Health and safety by contractors (if needed)
08.0901 Health physics
08.0902 Industrial safety

08.1000 Demobilization by contractors (if needed)

08.1001 Demobilization of project infrastructure for decommissioning

08.1002 Demobilization of personnel

09 Research and development

09.0100 Research and development of equipment, techniques and procedures

09.0101 Equipment, techniques and procedures for characterization

09.0102 Equipment, techniques and procedures for decontamination

09.0103 Equipment, techniques and procedures for dismantling

09.0104 Equipment, techniques and procedures for waste management

09.0105 Other research and development activities

09.0200 Simulation of complicated works

09.0201 Physical mock-ups and training

09.0202 Test or demonstration programmes

09.0203 Computer simulations, visualizations and three dimensional modelling

09.0204 Other activities

10 Fuel and nuclear material

10.0100 Removal of fuel or nuclear material from facility to be decommissioned

10.0101 Transfer of fuel or nuclear material to external storage or to treatment facilities

10.0102 Transfer of fuel or nuclear material to dedicated buffer store

10.0200 Dedicated buffer storage for fuel and/or nuclear material

10.0201 Construction of buffer storage

10.0202 Operation of buffer storage

10.0203 Transfer of fuel and/or nuclear material away from the buffer storage

10.0300 Decommissioning of buffer storage

10.0301 Decommissioning of buffer storage

10.0302 Management of waste

11 Miscellaneous expenditures

11.0100 Owner costs

11.0101 Implementation of transition plans

11.0102 External project to be performed as a consequence of decommissioning

11.0103 Payments (fees) to authorities

11.0104 Specific external services and payments

11.0200 Taxes

11.0201 Value added taxes

11.0202 Local, community, federal taxes

11.0203 Environmental taxes

11.0204 Taxes on industrial activities

11.0205 Other taxes

11.0300 Insurances

11.0301 Nuclear related insurances

11.0302 Other insurances

11.0400 Asset recovery

11.0401 Asset recovery related to redundant equipment

11.0402 Asset recovery related to released materials

11.0403 Asset recovery related to material and equipment from conventional dismantling and demolition

11.0404 Asset recovery related to buildings and site

11.0405 Other asset recovery

Appendix II

REVIEW SCHEMES FOR COSTING

The principal scheme for the calculation of workforce for hands-on decommissioning activities is presented in Fig. 15. Sources of data are the facility inventory database, database of unit factors, calculation item specific data introduced by the user at the keyboard and data calculated in the previous calculation steps. Steps in the calculation sequence are indicated from top to bottom in the flow chart below.

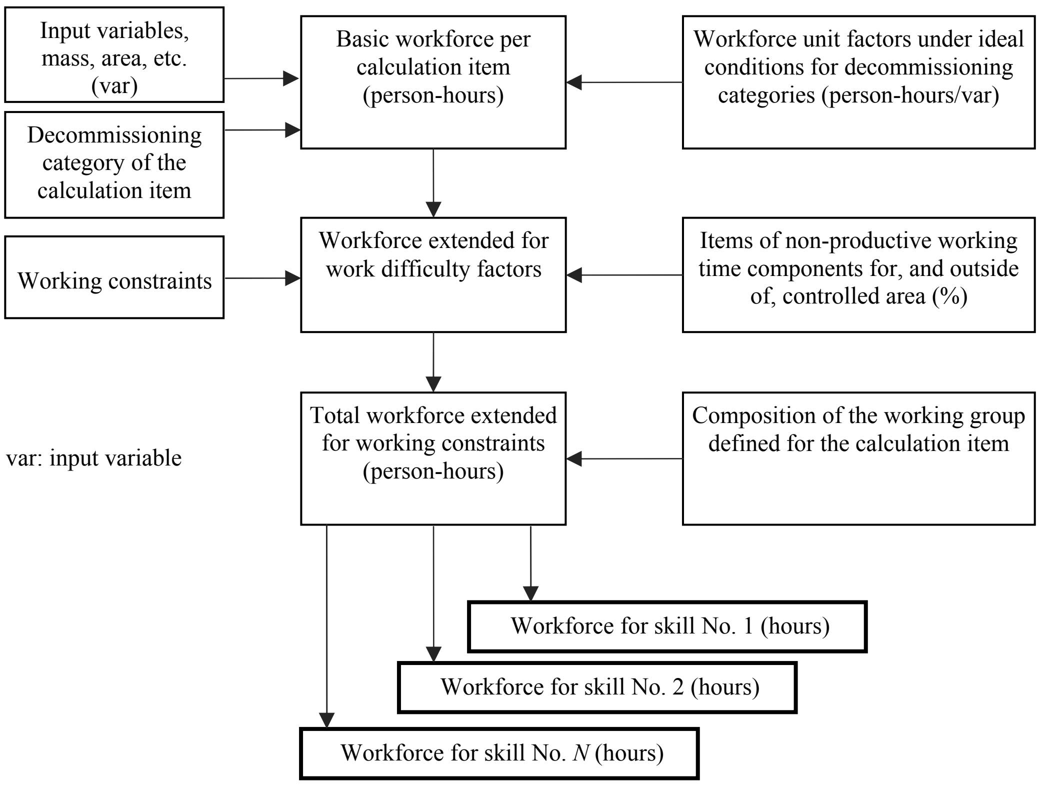

FIG. 15. Sequence for the calculation of workforce, duration and data for skills.

The workforce for the calculated hands-on activity is the product of the input variable, modified by work difficulty factors and the non-productive working time components. Workforce data are used for the calculation of labour costs. The sequence for calculation of labour costs is presented in Fig. 16.

Labour cost is calculated for each skill involved within the working group. The calculation procedure follows the recommendation of the ISDC [4] for the content of individual cost groups, which is, in this case, the components of the labour cost.

The calculation of investment cost components according to the definitions in Ref. [4] is presented in Figs 17 and 18. The procedures presented are used for the calculation of quantities of individual items and for the calculation of costs for these items. Investment cost components are calculated in four steps:

(i) Investment cost according to the consumption items with investment types (numbered 1 to *N* in Figs 16 and 17). Local national accounting legislation defines which items are defined as investment items, as an example based on the total cost of the item. In this case, the list of investment items should be defined. The investment items are calculated first as the quantities of individual items as the product of the input variable (the same as for calculation of workforce) and the consumption unit factor specific for the investment item. The cost values of individual investment items are calculated as the product of quantities of individual investment items and the unit cost factors for individual items.

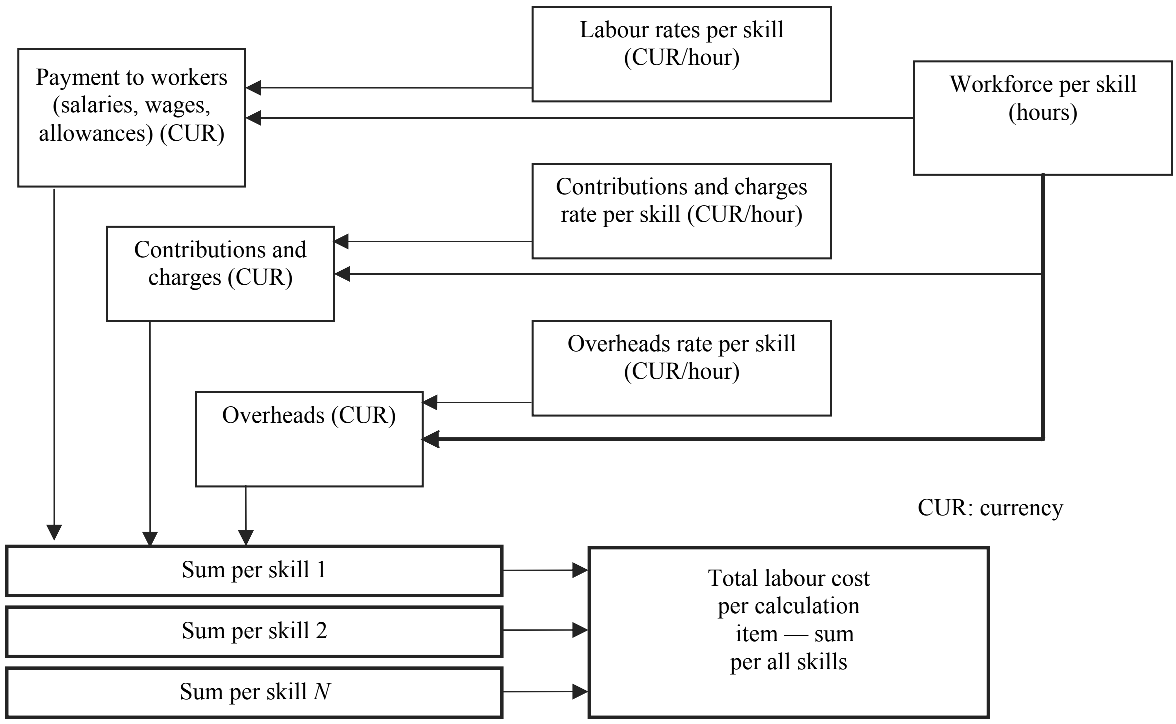

FIG. 16. Sequence for calculation of labour cost items.

(ii) Items not defined in the list of investment items, which also contribute to the investment costs, are calculated as one overall value as the product of the input variable (the same as for calculation of workforce) and the unit cost factors for non-specified investment items.

(iii) For investment costs dependent on the duration of the decommissioning activity, investment cost items can be identified that are proportional to the duration of the activity. This cost component is calculated as the product of the duration of the activity and the period specific cost value introduced to the calculation item.

(iv) Investment costs identified for the decommissioning activity as one-off costs are introduced to the calculation item directly. This value is added to the total investment cost of the calculation item.

The total value of investment cost is the sum of all of the investment cost items presented above. This approach enables the calculation of all cost components across the various types. The calculation includes not only total cost values of individual investment components, but also the quantities of individual items, in their physical units as available. The same approach is used for the calculation of expenses, presented in Fig. 18. A definition of expenses components is presented in Ref. [4]. In simplified calculations, only the overall investment cost unit factors are used, and a single step calculation instead of two step calculations is presented in Fig. 17. Calculations for period dependent investment costs and one-off costs are the same. The same is also used for the calculation of expenses.

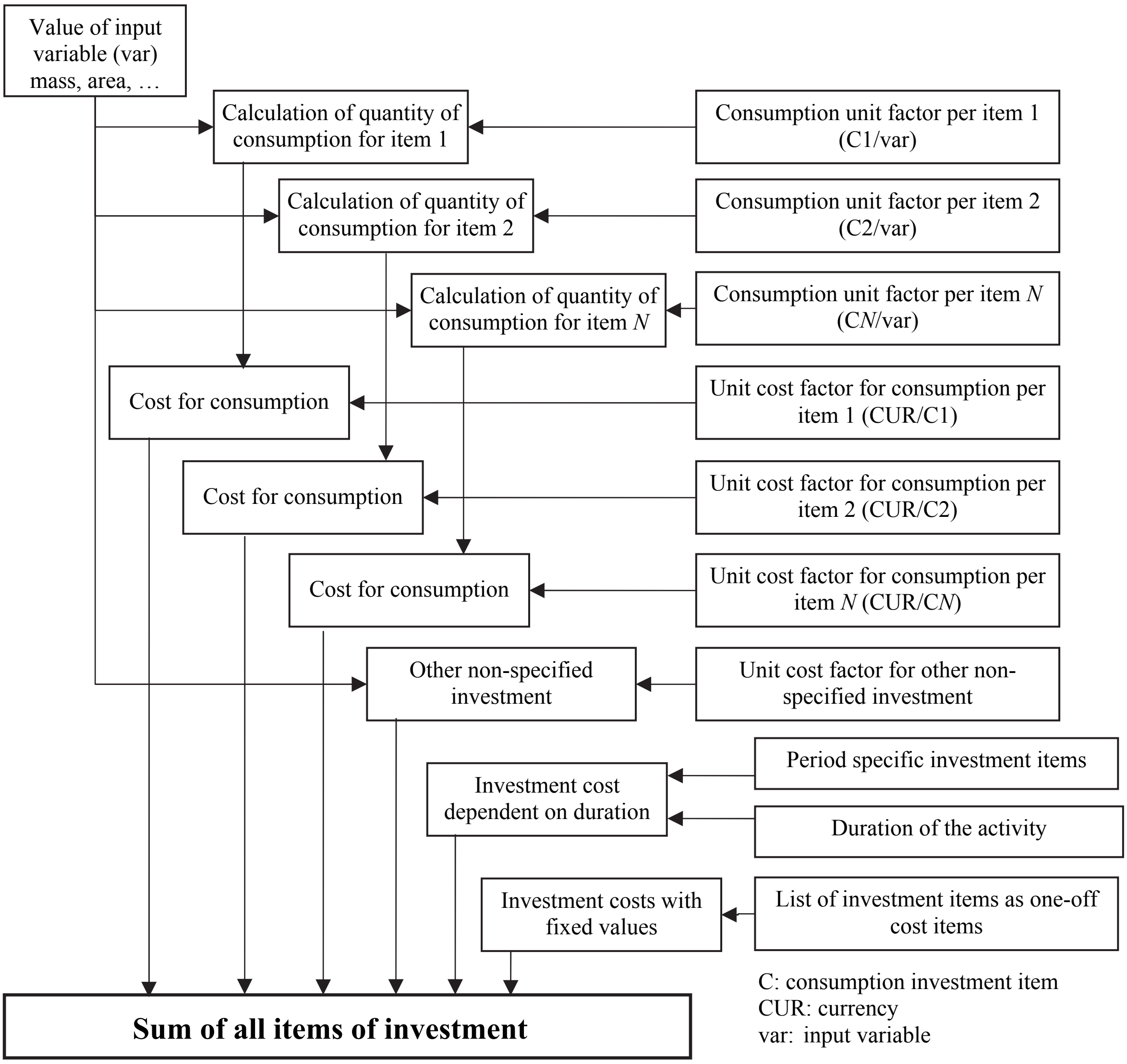

FIG. 17. Sequence for calculation of investment cost items.

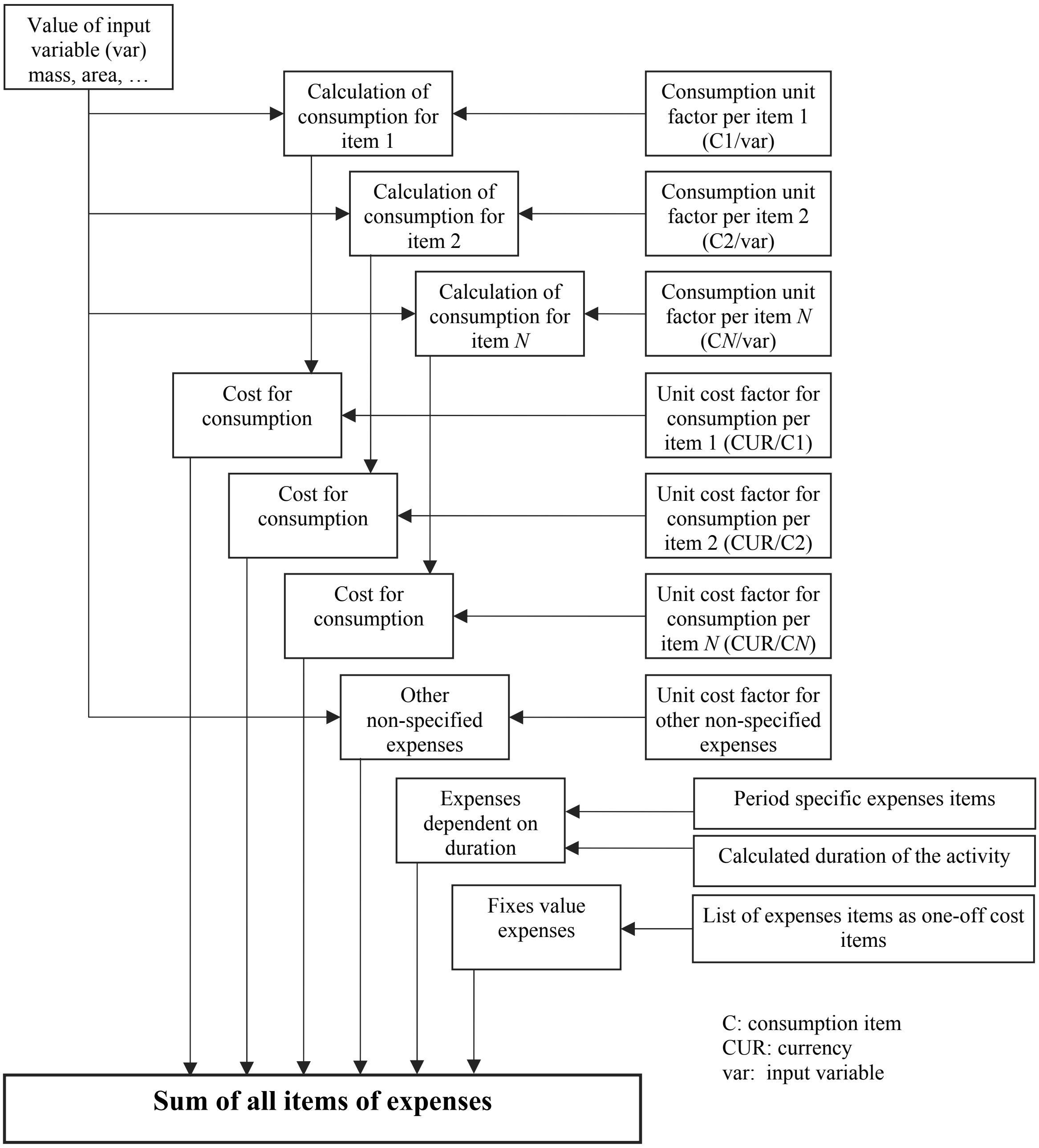

FIG. 18. Sequence for calculation of expenses cost items.

Appendix III

TYPES OF CALCULATION ALGORITHM

The calculation algorithms were developed for cost categories as defined in Section 9.3 and implemented as presented in the figures in Appendix II:

— Activity dependent costs, related to the extent of hands-on work such as dismantling;
— Period dependent costs, proportional to duration of individual activities/phases;
— Collateral costs and costs for special items.

Calculation algorithms for activity dependent costs:

$$y = F_s \times x \qquad (1)$$

where

y is the calculated parameter for decommissioning (units of the calculated parameter);
F_s is the specific unit factor (units of the calculated parameter/units of the variable);

and x is the input variabyle (weight, surface, etc., units of the variable).

Applications:
Calculation of workforce:

$$y = F_{mp} \times x \qquad (2)$$

where

y is the calculated workforce (person-hours);
F_{mp} is the workforce unit factor (person-h/units of the input variable):

and x is the input variable (mass, surface, etc., units of the input variable).

Consumption items — calculation of consumable material items or spare parts, technological consumables, etc.:

$$y_m = F_{ms} \times x \qquad (3)$$

where

y_m is the material consumable item (electrical energy, steam, etc.; units of the material item);
F_{ms} is the unit factor (units of the material item/units of the variable);

and x is the input variable (weight, surface, length, etc., units of the variable).

Cost of specific items of consumed materials or media are calculated on the basis of their relevant quantities. The calculation relationship is the product of the unit cost factor for a given material item and the already calculated material item of a consumable or an investment item, spare parts or technological consumable:

$$y_c = F_{cs} \times x \quad (4)$$

where

y_c is the decommissioning cost item (costs for electrical energy, steam, etc., currency units);
F_{cs} is the unit cost factor (currency units/units of the material variable (e.g. CUR/kW·h);

and x is the input variable (electrical energy, steam, etc., units of the material variable).

Cost of other consumables or investment cost are calculated directly on the basis of the input variable. The calculation relationship is the product of the unit cost factor for a consumable or an investment, unspecified for the individual material items (currency units/units of the input variable), and the input variable:

$$y_n = F_{cn} \times x_v \quad (5)$$

where

y_n is the cost of the decommissioning item (currency units);
F_{cn} is the unit cost factor (currency units/units of the input variable);

and x_v is the input variable (weight, surface, length, etc., units of the variable).

In some applications, mainly in the case of preparatory and termination activities, a calculation relationship occurs containing a constant that is independent of the input variable:

$$y = F_v \times x_v + \text{const.} \quad (6)$$

where

y is the calculated parameter of decommissioning (units of the calculated parameter);
F_v is the unit factor (units of the calculated parameter/units of the variable);
x_v is the input variable (weight, surface, length, etc., units of the variable);

and const. is a constant factor (workforce, etc., units of the calculated parameter).

For some elementary activities, there is only a constant factor. In these cases, tables of constant factors are developed, allowing the user to select the appropriate constant factor.

Calculation algorithms for period dependent costs

$$y = F_t \times T \quad (7)$$

where

y is the calculated parameter of the decommissioning (units of the calculated parameter);
F_t is the specific time dependent unit factor (units of the calculated parameter/time units);

and T is the duration of the elementary activity (time units).

Specific types can be:

- For consumable materials, i.e. for the calculation of material items of a consumable or investment nature, spare parts or technological media. The calculation is the product of the material consumable specific unit (units of the material item/time units) and the duration of the activity.
- For costs, unspecified, i.e. for the calculation of consumable or investment costs. The calculation is the product of the unit cost factor for the consumable or investment item, unspecified for the individual material items (currency units/time units), and the duration of the activity.
- Calculation of workforce for period dependent activities is the conversion of duration (in hours) into workforce (in person-hours) at the individual skill level.

Calculation algorithms for activities independent of input variables

$$y = \text{const.} \quad (8)$$

where

y is the calculated parameter of decommissioning (units of the calculated parameter)

and const. is a constant factor within the elementary activity (units of the calculated parameter).

In this case, the calculation algorithm presents the transformation of the input value to the value of the relevant output parameter and the location of the output parameter in time. A typical application is in the case of the calculation of workforce of some preparatory and finishing activities, oriented to the room, and in calculation items, where the various payment items, such as tax, interest, prices of devices and other constant financial items, are the subject of the calculation.

Appendix IV

CERREX SOFTWARE APPLIED TO A RESEARCH REACTOR OF THE GENERIC ARGONAUT TYPE

IV.1. INTRODUCTION

This appendix presents the results of a cost calculation for the dismantling of a research reactor of the generic ARGONAUT type, performed using CERREX, and compares the results with a cost estimate obtained by the facility owners.

The ARGONAUT reactor was first developed at the Argonne National Laboratories, USA. Typical roles and the main features of the ARGONAUT included:

— Participation in training activities in neutron flow and neutron activation analysis;
— Support for public research of irradiation of materials, implementation of analytical techniques using a neutron source and production of radioisotopes;
— Provision of similar services to companies under a contractual framework;
— A maximum power of 100 kW, with power typically between 1 and 100 W used for teaching purposes and up to 100 kW for irradiation.

The reactor was dismantled between 2006 and 2008. The duration of the decommissioning site works estimated by the facility owners was 13 months, assuming 21 working days per month and 8 working hours per day (8 × 21 × 12 = 2016 working hours per year, see cell V2 in the 'ISDC' tab). Furthermore, the owners assumed six workers to be present on-site at any given time (see cell L1 in the ISDC tab).

The people involved were:

— One project manager: 2 working hours for 21 working days per month for 14 months (13 months of dismantling + 1 month for the report), €70/h (see cell AC2 in the ISDC tab).
— One site manager: 8 working hours for 21 working days per month for 14 months (13 months of dismantling + 1 month for the report), €57/h (see cell AA2 in the ISDC tab).
— One health physicist: 8 working hours for 21 working days per month for 14 months (13 months of dismantling + 1 month for the report), €47/h (see cell Y2 in the ISDC tab).
— One team leader, paid €35/h (see cell X2 in the ISDC tab), active in all operations along with the workers.
— Three workers, paid €30/h (see cell W2 in the 'ISDC' tab), active in all the operations.

IV.2. DESCRIPTION

(a) ISDC tab

Preliminary remark: For some operations, the labour cost was input directly from estimated data (in column T: for example, see cell T80 dealing with the labour cost for the dismantling of the pool store) because the available data did not allow correct use of the software. As an example, for a specific operation, the work duration for the team leader was not the same as for the workers, but the software requires one and the same duration for a given task for all staff. Therefore, it was not possible to input 'duration' in column V and then use directly the resulting number of person-hours calculated by CERREX.

Meaning of item numbers in order of appearance:

01.0601: Cost of completing planning studies
04.0101: Cost of equipment

04.0201: Phase 1: Dismantling of the pool store (24 d):
- One team leader working 192 h (€6720) + 1.7 workers working 328 h (€9840)

04.0202: Phase 0: Site preparation (44 d):
- One team leader working 352 h (€12 320) + 1.4 workers working 456 h (€13 680)

04.0502: Phase 5: Dismantling of core components, canals, except the external reflector, the 'marble' (borated concrete) and the sole (the support concrete structure) (32 d):
- One team leader working 256 h (€8960) + 1.6 workers working 404 h (€12 120)

04.0505: Phase 7: Dismantling of the bulk of the reactor (126.5 d):
- One team leader working 1012 h (€35 420) + 2.2 workers working 2308 h (€69 240)

04.0601: Phase 6: Dismantling of the west thermal column, the external reflector, the 'marble' (49 d):
- One team leader working 392 h (€13 720) + 2.4 workers working 1008 h (€30 240)

04.0602: Phase 8: Dismantling of the sole (30.5 d):
- One team leader working 244 h (€8540) + 2.9 workers working 664 h (€19 920)

04.0701: Phase 9: Dismantling of the basement (15 d):
- One team leader working 120 h (€4200) + 2.4 workers working 312 h (€9360)

06.0401: Cost of consumables
07.0101: Cost of concrete cutting
07.0301: Dismantling of the control room (5 d):
- One team leader working 40 h (€1400) + 2 workers working 80 h (€2400)

07.0303: Dismantling of the stack (5 d):
- One team leader working 40 h (€1400) + 2 workers working 80 h (€2400)
- Cutting cost (€6000) + equipment (€5000) + waste (€24 150)

07.0402: Refurbishment of the reactor hall floor:
- Subcontracting: €70 000

08.0101: Site manager cost
08.0207: Project manager cost
08.0301: Health physicist cost
11.0104: Transport and bonus cost
04.0201.01: Phase 2: Dismantling of 'cimetière vertical', a side room to the hot workshop (19 d):
- One team leader working 152 h (€5320) + 0.9 worker working 152 h (€4560)

04.0201.02: Phase 3: Dismantling of the hot workshop (17 d):
- 0.8 team leader working 128 h (€4480) + 1.3l workers working 224 h (€6720)

04.0201.03: Phase 4: Dismantling of the 'cimetière horizontal', a side room to the hot workshop (15 d):
- One team leader working 120 h (€4200) + 1.4 workers working 184 h (€5520)

04.0201.04: Phase 10: Site release activities (16 d):
- One team leader working 80 h (€2800) + 1.8 workers working 248 h (€7440)

(b) Inventory tab

For the work difficulty factors, average values from those proposed in the CERREX user's manual were assumed.

The following categories were added: Stainless linings (INV31) and Aluminium linings (INV32) dealing with stainless and aluminium elements, with the same coefficients as steel in the ISDC tab (see cells CE8 to CE10 and CF8 to CF10 in the ISDC tab).

IV.3. RESULTS

Two calculations were performed, one of which used the default data in the software to calculate waste volumes resulting from dismantling operations ('CERREX default') and one that used the waste volumes estimated by the facility owner ('CERREX'). For completeness, the actual amounts of waste sent for disposal are also provided for comparison.

For the file **Test.xlsx:** part 05, national disposal costs for the LLW, VLLW and conventional wastes (DC10, DD10 and DJ10) were used. They were based on container cost data from the national waste management agency.

In contrast, in the file **Test Default.xlsx**, the default data were not changed.

IV.3.1. Waste weights

Table 2 provides data on waste weights.

TABLE 2. WASTE WEIGHTS

Waste (t)	CERREX and CERREX default (t)	Actual data (t)
LLW	52.6	66
VLLW	139.8	367
Conventional	607.1	293

Differences noticed for the VLLW and the conventional wastes result from the national approach to zoning entire areas of nuclear installations as ‘radioactive’ or ‘non-radioactive’, i.e. all waste originating from the former is assumed to be radioactive and will require disposal in appropriate facilities. The option of ‘clearance’ for very low activity waste is not applied.

IV.3.2. Total waste costs

Table 3 provides data on waste costs with a similar labour cost (€15 200 for LLW, €7600 for VLLW and conventional wastes).

TABLE 3. WASTE COSTS

Waste	Estimated results from the facility owner (€)	CERREX (€)	CERREX default (€)
LLW	145 498	177 097	306 243
VLLW	81 107	91 873	85 278
Conventional	55 015	80 041	11 699
Total	**281 620**	**349 011**	**403 220**

The default data result in a significant overestimation of the costs for LLW, whereas the costs for conventional wastes are significantly underestimated. When the same disposal costs as assumed by the facility owner are used, the results are much closer.

IV.3.3. Total costs in euros

Table 4 provides total cost data.

TABLE 4. TOTAL COSTS

Estimated result from the facility owner (€)	CERREX (€)	CERREX default (€)
1 799 684	1 965 727	2 019 937

The difference between CERREX and the estimated results from the facility owner is only 9.23%, which is exceedingly good.

Similarly, the difference between the CERREX default and the estimated results from the facility owner is only 12.24%.

Appendix V

CERREX SOFTWARE APPLICATION AT BUDAPEST RESEARCH REACTOR (BRR)

V.1. INTRODUCTION

The BRR is a Russian designed WWRS-M10 reactor (Figs 19 and 20). It is a tank type, light water cooled and moderated research reactor. Its main goal is radioisotope production and neutron physics research. The BRR went critical in 1959 and during 52 years of operation, two modernizations and one partial decommissioning were carried out. After the second modernization, the reactor restarted in 1993. The planned lifetime is 30 years, and final shutdown will be in 2023. After the final shutdown, there will be a 2 year transition period and then partial decommissioning. The final goal is to dismantle the reactor system, most of the auxiliary systems and subsystems and hand the reactor building over to the Hungarian Academy of Sciences as an unrestricted site.

The organization operating BRR has, since 2004, participated in the IAEA regional TC project RER/3/009 on Support in Planning for the Decommissioning of Nuclear Power Plants and Research Reactors. The first Preliminary Decommissioning Plan (PDP) was developed in 2005 and followed IAEA recommendations. A revised PDP utilized IAEA guidance given in Ref. [9]. The IAEA Expert Mission to discuss the decommissioning planning of the BRR was organized in 2010.

The PDP database and the study of earlier decommissioning is the basis of CERREX software ‘Inventory’ and ‘ISDC’ work-sheets, despite the fact that the PDP structure is different from the CERREX structure.

V.2. GENERAL INFORMATION

Official name: Budapest Research Reactor
Address: 1121 Budapest, Konkoly Thege út 29–33
Postal address: H-1525 Budapest 114, P.O.B. 49, HUNGARY
URL: http://aekiweb.web.kfki.hu/index.php?page=&lang=en
Owner: Hungarian Academy of Sciences
Operational organization: Hungarian Academy of Sciences, KFKI Atomic Energy Research Institute
Supervision: Hungarian Atomic Energy Authority
URL: http://www.oah.hu/web/v2/portal.nsf/index_en
Responsible decommissioning organization: Public Limited Company for Radioactive Waste Management (PURAM)
URL: http://www.rhk.hu/en/

V.2.1. Reactor

Type: WWRS-M10, light water cooled and moderated tank type reactor
Thermal power: 10 MW(t)
Fuel: WWR-M2; enrichment 19.75%
Maximum thermal neutron flux: 2×10^{14} n·cm^{-2}·s^{-1}
First criticality: 1959
Modernization and upgrades: 1967, 1986
Incident or accident: None since 1959
Planned final shutdown: 2023
Transition period: 2023–2025
Decommissioning: 2025–2027.

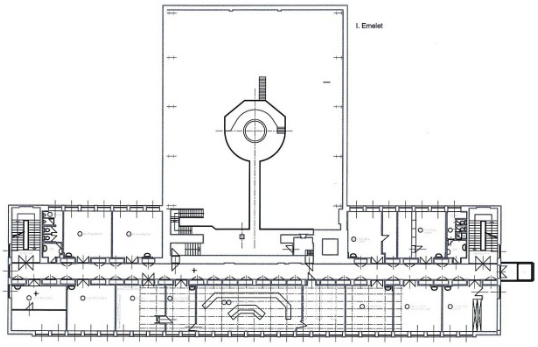

FIG. 19. Reactor building, cross-section.

FIG. 20. Reactor building, front view.

V.2.2. Reactor operating history

- 1959–1967: The initial thermal power was 2 MW(t) using low enrichment fuel (type EK-10). Performance was 20 000 h (1835 MW·d).
- 1967–1986: The power was increased from 2 MW(t) to 5 MW(t), using a new type of fuel and a beryllium reflector. Performance was 60 000 h (10 180 MW·d).
- 1986–1992: Full scale reconstruction and modernization; the power was increased to 10 MW(t). This was equivalent to partial decommissioning and occurred without incidents or accidents and additional dose.
- 1993–2008: The reactor performance was 49 600 h (20 320 MW·d).
- 2003. First periodic safety report. The regulatory body did not find any substantially important issues or events. The operating licence was extended for 10 years.
- 2008: The first batch of spent fuel was transported back to the Russian Federation as part of the Russian Research Reactor Fuel Return Program project.
- 2009: The core conversion from high enrichment fuels to low enrichment (19.75%) fuels began.

During the period from 1959 to 2010, there were no incidents, accidents, contamination events or unauthorized release of radioactive materials from the site. No events on the International Nuclear and Radiological Event Scale at levels 1–7 have occurred.

V.2.3. Licensing

According to Hungarian legal framework, the Hungarian Atomic Energy Authority issues the operating licence. The operating licence is undetermined, but the periodic safety report must be renewed every 10 years.

V.3. DESCRIPTION AND REMARKS FOR THE ‘ISDC’ WORK-SHEET

V.3.1. General remarks

- Necessary human resources. On the basis of the earlier decommissioning, the BRR intends to carry out the decommissioning tasks using BRR operational staff as follows:

  — Project management: eight to ten people.
  — Mechanical area: five or six workers.
  — Electrical area: five workers.
  — Radiation protection area: five workers.

  The staff composition is ten engineers, seven or eight technicians and seven or eight skilled workers. This staff will perform the dismantling activities, the radioactive waste management and the maintenance. Safeguards services will be provided by the KFKI Campus.

- The fixed and period dependent cost estimate data (columns R–U) are rough estimates since the reactor will operate until 2023:

Cell V2: The working time is 40 h per week. In one working year, the average working weeks are 48 with ~4 weeks of holiday. The working hours per year are 48 × 40 = 1920 h. Remark: During the transition period, some workers may work part time.

02.0102: This activity requires nine people for defuelling the active core and transporting the spent fuel assemblies to the away-from-reactor storage. The time required is 3 weeks. To rent a transport trolley and driver, €1000 is required.

02.0104: Expenses required for the licences (local and international).

02.0202: Expenses required for managing the ~30 m^3 of contaminated water.

02.0300: For equipment (e.g. high pressure washing machine), €3000 is required, and for chemistry and other materials, €5000 is required.

02.0400: For radiation protection measurements, €5000 of purchases are required.

04.0100: For the purchase of the special dismantling and demolition equipment (cutting, compaction devices, radioactive waste control and measurement equipment with certification), €150 000 is required, and for development of the required technology, €40 000 is required.

04.0200: For contingency for unforeseen events, €3000 of expenses are required.

04.0400: Removal of hazardous materials requiring specific procedures, i.e. toxic, poisonous and flammable materials. Contractors will carry out some of the work.

04.0501: Active core elements and beryllium reflector. To manage the beryllium final disposal, €15 000 is required, and for the development of a specific storage technology, €5000 is required.

04.0502: Expenses and investment costs required for the segmentation of ‘old’ and ‘new’ vessels.

04.0503: Expenses and investment costs required for special cutting machines, e.g. laser torch, hoists, frames, stands.

04.0506: The BRR considers two demolition technologies for concrete, referenced from the Rossendorf Research Reactor (Germany) and the DR2 Research Reactor (Denmark) final reports for decommissioning. Firstly, cutting with diamond wire, and secondly, using a concrete breaker (BROKK technology).

04.0601: Refers to decommissioning of chemistry laboratories, hot cells, secondary loop, pressurized air pipelines, workshops, electric switch rooms (not all), etc. The demolition phases are worked out in detail in the decommissioning plan, i.e. necessary human resources, timetable, radioactive waste quantity.

04.0700: To be carried out in several steps, but difficult to estimate precisely. Remark: Decontamination of the surfaces of contaminated systems and removal of the contaminated material will be performed during the transition period and during the decommissioning period. These activities will require six people and 2.5 months full time.

04.0800: Considers the outside area, which is expected to be clean, except for the ventilation pipes and shafts and around the radioactive waste stores.

04.0900: For a high sensitivity gamma camera and supplementary devices.

05: ‘Waste processing, storage and disposal’. The BRR calculates the radioactive waste quantity will be ~300 m^3 (intermediate and low level wastes). Hungarian Radioactive Waste Repository Ltd estimate transport and disposal as €1080/m^3. Additional costs are involved in sorting and preparation of the waste packages.

05.1200: For 100 t of metal scrap (minus €60 000).

06: ‘Site infrastructure and operation’. The BRR staff will carry out maintenance during the transition and decommissioning periods. This requires five people and 4.5 years full time. €15 000/year is required for the spare parts and hand tools.

07.0100: For conventional hand tools and single purpose tools for specific dismantling steps.

07.0200: For digging out the pipelines and emptying the buildings not to be demolished. Remark: The reactor building is not to be demolished. Some light structures easily demolished such as stores and machine room may be demolished — to be decided.

07.0400: Requires four people and ~5 months full time. The expenses are for agricultural land, trees and plants.

07.0500: Line 115 contains the gamma camera price. For biological remediation (plant, trees, grass, etc.), expenses of €5000 are required.

08.0100: For new furniture, offices, computers, etc.

08.0200: Expenses of €15 000/year for ongoing studies, quality assurance programme development, planning and public relations activities as for similar large projects. Considered to be a special task.

08.0300: As above.

08.0400: For protective clothing, respiratory masks and other personal protection equipment (€10 000/year); €3000/year for special protective tool development.

08.0500: As 08.0100.

09.0100: Since effective decommissioning activities will be in 2025, 2 × €10 000 is allowed as normal practice for special tool development.

09.0200: For cold tests and inactive tests with materials.

10.0100: For 590 spent fuel elements for transshipment to the Russian Federation. The calculation is based on a transshipment made in 2008.

11.0100: For electricity, water (with sewerage), gas and fees to the authority.

11.0402: For recycling materials from clean areas, €80 000 is required.

V.3.2. Remarks for the Inventory work-sheet

INV1 (BA column): The solid radioactive waste quantity is expressed in cubic metres in the decommissioning plan; this has been changed to tonnes as a rough estimate.

V.4. EVALUATION

V.4.1. Workforce

The CERREX software calculated 239 214 person-hours, in contrast with the PDP, where a workforce of 79 500 person-hours was calculated. This is a significant difference, and there are two important reasons for this:

(i) The people who will carry out the decommissioning can be regrouped and rearranged. The BRR wishes to employ ~25 employees continuously. These workers will perform different tasks, unlike in the earlier decommissioning. The BRR only intends to employ contractors for the thermal cutting and bioshield demolition tasks.

(ii) Duration. The shortest time period in the CERREX table is 0.1 year, equating to 1.2 months or 5–6 weeks. Some work phases will last 1 or 2 weeks on the BRR site.

V.4.2. Costs

The CERREX calculated costs are €4 455 361. Costs of €3 268 500 were calculated in the PDP. The difference is 36%, which is a significant disparity due to the differing person-hours. Accordingly, it is necessary to revise the PDP human resources data to enable the CERREX table to be filled in more precisely. Another difference is that the contingency is 20%. The PDP calculated 5% spare costs only; the 20% contingency is thought to be more realistic. The other input data and results are acceptable.

Appendix VI

CERREX SOFTWARE APPLICATION TO THE JAPAN RESEARCH REACTOR No. 2 (JRR-2) DECOMMISSIONING PROGRAMME

The JRR-2 was a heavy water moderated and cooled CP-5 type research reactor. It used highly enriched uranium fuels to obtain a neutron flux of 1.8×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ and achieve 10 MW thermal power. The reactor first went critical in October 1960 and was used for neutron scattering experiments, irradiation tests of nuclear fuels and materials, radioisotope production, boron neutron capture therapy, etc. The JRR-2 was finally shut down owing to degradation of the facility after 36 years of operation.

The JRR-2 decommissioning project started in August 1997. The project was divided into four major phases:

- Phase 1: Preparation (shutdown related activities).
- Phase 2: Isolation of cooling systems and the reactor body.
- Phase 3: Tritium decontamination and dismantling of cooling system components.
- Phase 4: Removal of the reactor vessel and dismantling of remaining facilities.

Activities implemented within Phases 1–3 were completed by 2005. The reactor vessel has been isolated for safe storage until Phase 4 begins.

The major activities are listed in Table 5.

The actual expenditures of the contractual work are as follows:

- Phase 1: 62 000 000 yen (€470 000).
- Phase 2: 200 000 000 yen (€1 500 000).
- Phase 3: 356 000 000 yen (€2 700 000).

TABLE 5. DECOMMISSIONING DATA FOR JRR-2

Decommissioning activities	Cost items	Activity duration (days)	Number of workers	Metal waste (kg)	Concrete waste (kg)	Others (kg)
Phase 1: Preparation			JAEA staff: 19			
1 12. Deactivation of reactor	2.010 1	2	3	540	—	12
2 13. Drainage and transport of heavy water	2.020 4	25	10	—	—	132
3 14. Drainage of light waste used for thermal shielding	3.010 3	52	2	—	—	—
4 15. Rearrangement of heavy water storage facility	3.020 4	146	25	7 540	—	1 948
16. (1) Dismantling of piping and equipment						
17. (2) Confirmation of soundness of existing tanks						
18. (3) Replacement of piping and equipment						
Phase 2: Isolation of cooling systems and the reactor vessel			JAEA staff: 14			
1 19. Sampling for radioactive inventory estimation	5.090 1	31	9	—	—	—
20. (1) Sampling of contaminated materials				311	—	78
21. (2) Sampling of radioactive materials				—	41	120

TABLE 5. DECOMMISSIONING DATA FOR JRR-2 (cont.)

Decommissioning activities			Cost items	Activity duration (days)	Number of workers	Metal waste (kg)	Concrete waste (kg)	Others (kg)
2	22.	Isolation of reactor cooling systems and facilities	3.010 4	72	14	5 632	20	1 098
	23.	(1) Isolation of heavy water piping systems						
	24.	(2) Isolation of light water piping systems for thermal shielding						
3	25.	Removal of fuel exchange cask and others	4.060 2	23	9	16 645	—	132
4	26.	Transport of heavy water	4.040 3	61	10	—	—	147
5	27.	Removal of experimental equipment and others	4.060 1	56	22	238 085	12 115	776
6	28.	Isolation of reactor vessel	3.010 2	115	18	3 529	—	550
7	29.	Dismantling of secondary cooling system components	7.020 2	104	10	1 755	—	90
8	30.	Partial dismantling of radiation control facilities	4.020 1	13	6	487	—	39
Phase 3: Tritium decontamination and dismantling of cooling system components					JAEA staff: 28			
1	31.	Decontamination of components (I, II)	2.030 1	382				
	32.	(1) Component decontamination test I			29	111		1 632
	33.	(2) Component decontamination test II			24	4 712		3 069
2	34.	Partial dismantling of emergency electricity supply source		85		—	—	—
3	35.	Dismantling of neutron monitoring devices	2.050 8	91	3	—	—	—
4	36.	Partial dismantling of gaseous waste exhausting facility	5.010 5	39	13	512	—	200
5	37.	Drainage of water in spent fuel storage pool and dismantling of components	4.030 1	59	14	8 821	355	2 247
	38.	(1) Removal of spent fuel handling devices and others						
	39.	(2) Dismantling of water treatment devices						
	40.	(3) Drainage of pool water						
	41.	(4) Decontamination and painting of pool walls						
6	42.	Dismantling of components in reactor cooling system facilities	4.050 3	332	85	8 243	224	21 194
	43.	(1) Removal of control panel, cables and others						
	44.	(2) Removal of installations relating to heavy water treatment systems						
	45.	(3) Removal of heavy water system components						
	46.	(4) Tritium decontamination of heavy water system components						
	47.	(5) Dismantling of components in non-controlled area						

TABLE 5. DECOMMISSIONING DATA FOR JRR-2 (cont.)

Decommissioning activities			Cost items	Activity duration (days)	Number of workers	Metal waste (kg)	Concrete waste (kg)	Others (kg)
7	48.	Dismantling of fresh fuel storage rack	4.060 2	8	5	741	—	218
8	49.	Partial dismantling of radiation control facilities	4.020 1					
	50.	(1) Dismantling of stack gas monitor device		2	3	284	—	—
	51.	(2) Dismantling of neutron area monitor device		8		30	—	—
9	52.	Dismantling of monitoring/control system facilities	7.020 3	10	9	18	—	—
	53.	(1) Confirmation measurement						
	54.	(2) Classification and transport						
10	55.	Sampling for radioactive inventory estimation	2.040 1	154	17	—	334	2 335
	56.	(1) Sampling of concrete materials in reactor building						
	57.	(2) Sampling of steel materials in reactor building						
	58.	(3) Measurement of radioactivity						

Note: JAEA: Japan Atomic Energy Agency.

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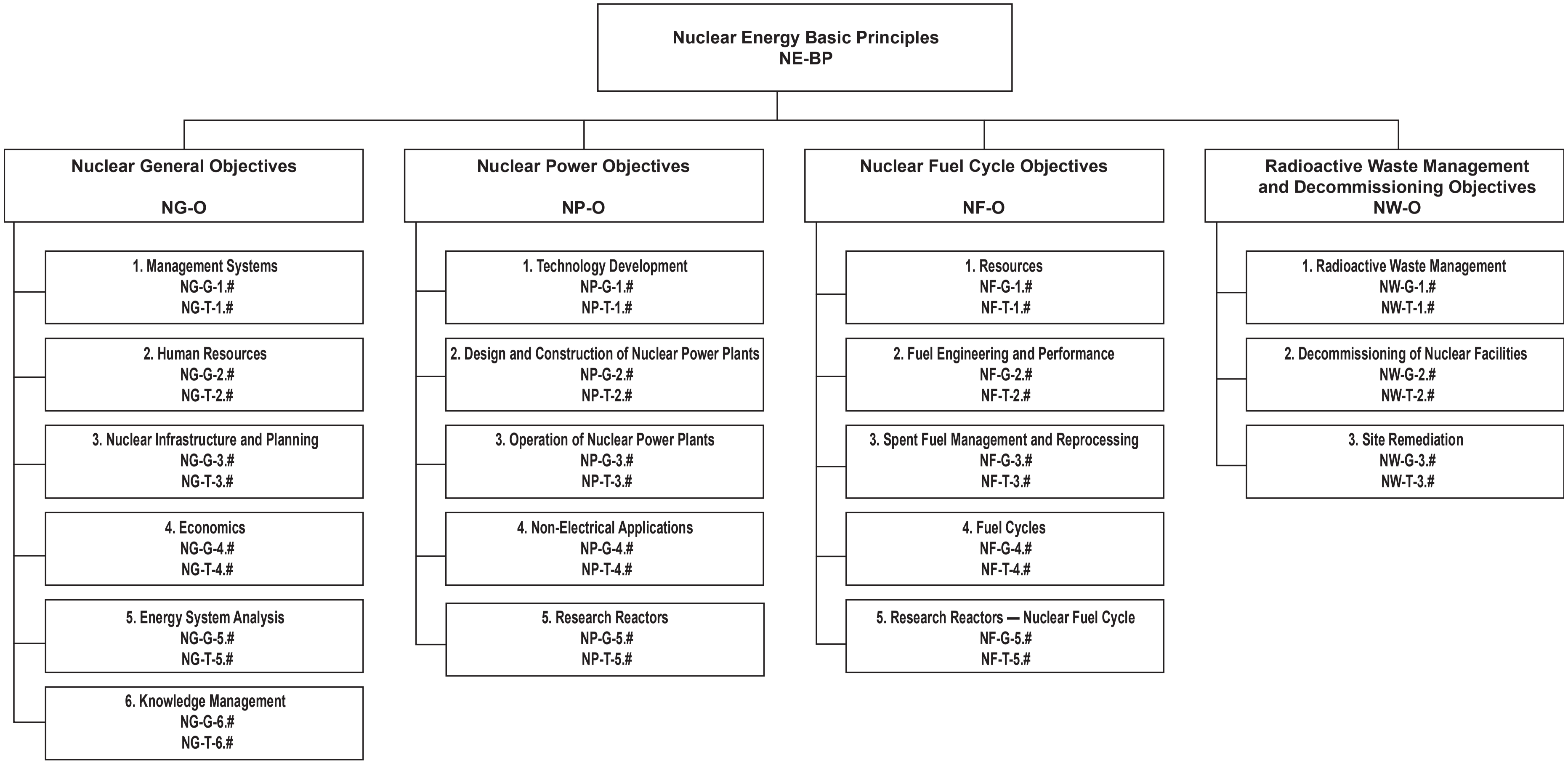

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ISSN 1995–7807