Process structure as a basis for the planning stage of project management for the decommissioning of nuclear facilities

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1 Introduction

In Germany the first nuclear power plants were built and put into operation in the 1950s. In the 1960s, 1970s and 1980s further nuclear facilities were commissioned [1]. After operating times of more than 40 years these facilities will be decommissioned due to technical, economic or political issues and subsequently will be dismantled. Until now only ten reactors have been dismantled yet [2]. According to the International Energy Agency (IEA) the worldwide number of nuclear facilities that need to be decommissioned and dismantled will increase considerably in the coming years [1] [2] [3]. The European Commission estimates that by 2025 more than a third of the 143 reactors in the EU-27 will be shut down and dismantled [4]. In its World Energy Outlook 2014 the IEA expects that until 2040 nearly 200 reactors need to be decommissioned and dismantled worldwide [2]. Therefore the planning process of decommissioning and dismantling becomes the focal point of interest for parties involved, namely plant operators, government agencies and dismantling companies.

The results of finished and ongoing demolition projects demonstrate that despite the uniqueness of each plant the dismantling of nuclear power plants is technically safe. Aside from the challenging dismantling process, the economic analysis has a very strong influence on the planning and execution of nuclear decommissioning projects. Furthermore it has been shown that the utilisation and implementation of classic civil engineering planning, project management standards, generalisation, assumptions and techniques is problematic. Due to the lack of experience data from finished and ongoing decommissioning projects show significant deviations from the initial schedule and cost plans [5].

In order to reduce or eliminate critical exceedances new planning methods with an approach to quantify economic effects of different disassembly variants are necessary. Therefore uncertainties that affect the duration and costs of a decommissioning project need to be involved in the planning very first. This approach allows an economically optimal and robust decommissioning planning. Precondition for an efficient overall planning is a structured planning process. The planning process is divided into two blocks "data collection and processing" and "methodical determination of an integrated schedule, cost and resource plan".

This paper describes new approaches for the planning and the respective requirements for supporting the addressed problem. The effects of the used method and its relationship to the block "data collection and processing" will be explained. Finally the data collection and processing will be examined via a work breakdown structure. The procedure for creating a work breakdown structure and its formatting will be explained using results from the research project MogaMaR.

2 New approaches for the planning of the decommissioning of nuclear facilities and the importance of the work breakdown structure

The decommissioning of nuclear facilities can be characterized according to the definition of the German DIN 69901-5 [6] as a "project". The time limitation, the complexity, the relative novelty and uniqueness of the tasks are the main features that classify each decommissioning of a nuclear facility as a project. Projects and the steering process through the phases of a project (the so-called project management) are described in various standards such as the PMBOK Guide, the ICB, PRINCE2, the ISO 21500 or the DIN 69901 [7] [8] [9] [10] [11]. In order to successfully dismantle nuclear facilities the proposed measures in the standards of project management should be considered. These standards are quite similar in their approaches to project management. The planning phase includes the scheduling, cost and financial planning, and the resource and procurement planning. For the detailed planning various methods are proposed.

The traditional understanding of project management is based on a deterministic scheduling with the perfect predictability of all activities. The different plans such as scheduling, cost and resource planning are based on each other but are not really interconnected. All actions are determined by a logical and technically necessary sequence of activities [12]. In general, at first a schedule, the resources and the procurement will be planned. Based on these plans the costs of the project and a financing plan are derived. Mutual influences and sensitivities between the schedule and costs generally are not considered (among others [12], [13]).
In reality it appears that projects are becoming more complex. The consideration of the interaction and interdependence of different actors and activities of a project lead to an increased complexity in project planning and to more accurate plans at the same time [14] [15]. Based on the traditional understanding of project management the so-called project management 2nd order (PM-2) was developed. In addition to the planning of the traditional project management the PM-2 takes also dynamics, uncertainties, schedule changes and interdependencies into account [15].

Due to the lack of experience in the nuclear decommissioning the processes are not predictable in a deterministic way. Both the sequence and duration of activities cannot be forecasted precisely. For this reason the traditional application of a deterministic scheduling approach does not provide an accurate picture of the decommissioning process and leads to uncertainties in the dismantling activities that are not considered in the planning. Because of the complexity of the decommissioning of a nuclear power plant the decommissioning planning according to the PM-2 approach is expedient. Especially an integrated view of various factors (especially the integrated schedule, cost and resource planning) using stochastic methods should be considered. At the same time a robust decommissioning plan should be created, which provides an optimal solution for various decommissioning scenarios and thus considers uncertainties of the decommissioning activities. The aim should therefore be the determination of a robust plan of the decommissioning activities using stochastic methods.

As a basis for the planning the standards mentioned above define the scope and a macro structure of the project [7] [8] [9] [10] [11]. Based on the macro structure a work breakdown structure (WBS) and the work packages are planned. The WBS is a key element for the implementation of a project as it is a complete list of every single step of a project. In the following it is assumed that the WBS includes every single activity for the decommissioning at the site. Planning and approval activities are not covered in the WBS but rather result from the WBS and influence the calculation of an integrated decommissioning plan (Fig. 1). Beside the duration it is useful to assign for every single step further properties such as the resources that are needed, costs and precedence relationships. The selection of data which are necessary to calculate an integrated schedule, cost and resource plan depends on the method that is used.

The relevance of the WBS for the entire project management and in particular for the project planning will be clear by the consideration of the entire planning horizon (Fig. 1). As an input-element of a method for planning the decommissioning and for the preparation of the approval documents the WBS is a key element for a reliable planning and demolition.
The data summarized in the WBS are combined using a method so that an integrated schedule, cost and resource plan can be created taking into account stochastic sequences and durations of several activities. The requirements for an appropriate method result from the characteristics of the PM-2 approach presented above. The requirements and the method according to the PM-2 approach will not be considered in detail in this work (an explanation on the method can be found, among others, in [14] and in future releases of the authors).

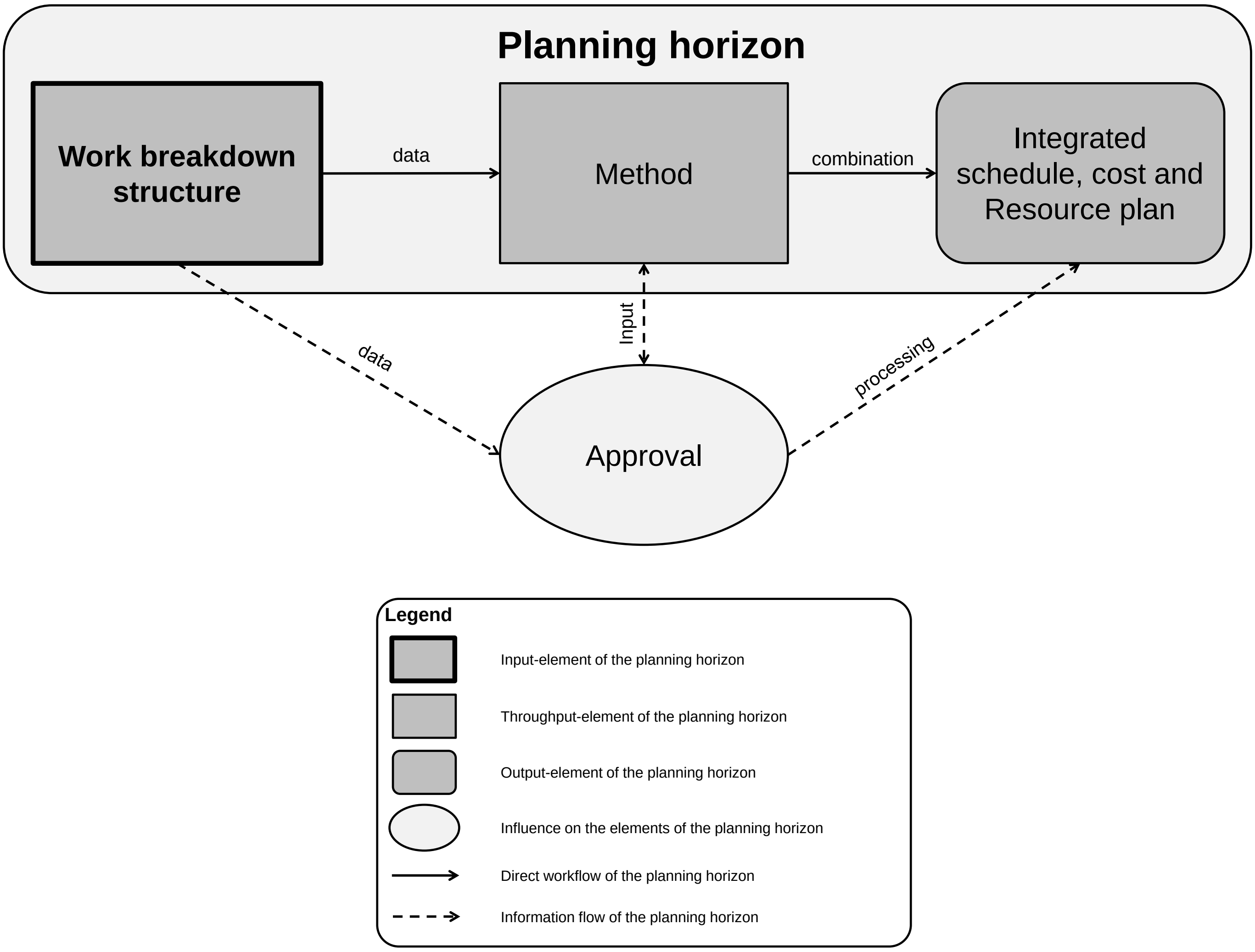

Fig. 1. Work breakdown structure as an input-element for the integrated schedule, cost and resource planning

For the creation of a reliable and accurate plan two blocks are relevant: on the one hand, a suitable method should be used. On the other hand data have to be developed and prepared in a work breakdown structure (Fig. 1). The block “data collection and processing” by using a work breakdown structure is described in more detail below.

3 Formatting the work breakdown structure

For the development of a work breakdown structure at first it is necessary to define which work hast to be done to finish the project successfully. All activities have to be identified and listed. For every activity data is required for the integrated planning process. Depending on the required data it can be determined where and how the data has to be collected. Finally the data in the WBS must be processed so that they can be used by the method (Fig. 2).

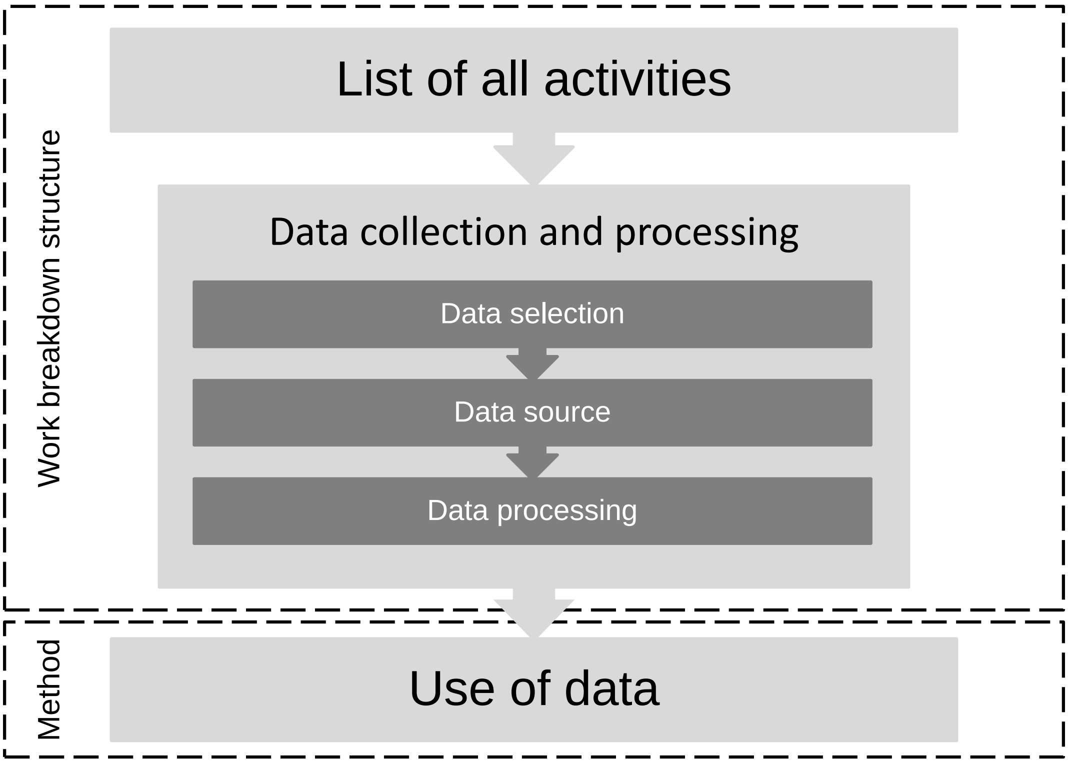

Fig. 2. Steps to create a work breakdown structure

For using the data it is important to format them consistently. The formatting is necessary to interpret the data by using a method. The formatting of the data has an important influence on the planning result, since only uniformly formatted data can be taken into account by the method. To simplify the whole processing process data are recognized in a work breakdown structure with a specified formatting. The required data can be entered directly by using the formatting in the WBS (Fig. 3).

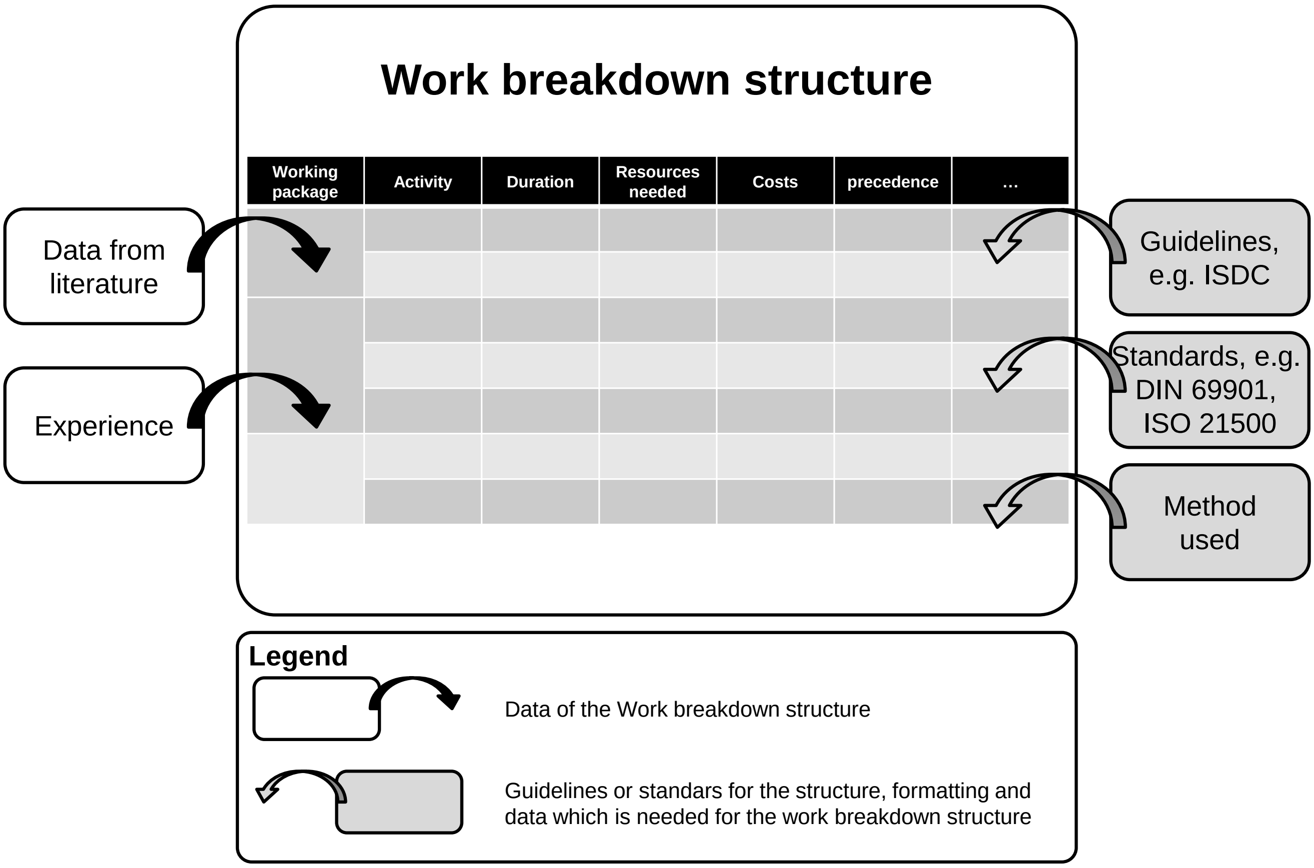

Fig. 3. Data import and process structure of the work breakdown structure

In the research project "Model development of a holistic project management system for nuclear decommissioning projects" (MogaMaR), which is funded by the German Federal Ministry of Education and Research (BMBF), the described procedure is developed and applied. The aim of the project partners Karlsruhe Institute of Technology (KIT), AREVA GmbH and VKTA – Strahlenschutz, Analytik & Entsorgung Rossendorf e.V. is to investigate an economically optimal and robust planning for the decommissioning of nuclear facilities taking technical possibilities and ecological issues into account.

At first all activities of the nuclear decommissioning are identified and listed. For this purpose the knowledge and experience of the project partners concerning the decommissioning of nuclear facilities will be collected in an experience database. The collection of data implies the analysis of work breakdown structures, approval documents and other project documentations of completed and ongoing dismantling projects. The knowledge should be further supplemented by data from the literature. Once the experience database is filled with data, it becomes a work breakdown structure and can be used by a method. The most detailed description of the steps in the experience database is represented by so-called "activities". The activities are combined to form "sub work packages" which are combined to form "work packages". Several work packages form a "decommissioning phase" (Fig. 4). The data collected for each activity are shown in Fig. 5-7.

The mapping of the collected knowledge and experiences in the database is done process-oriented. This means that the data is assigned to the suitable activities. On the one hand the resulting structure is based to the German DIN 69901-2 and the ISO 21500. On the other hand the so-called "International Structure for Decommissioning Costing (ISDC) of Nuclear Installations" [16] of the Nuclear Energy Agency (NEA) takes impact on the structure of the experience database. In the ISDC various steps are hierarchically grouped together as so-called Principal Activities [16].

Following the requirements of the ISDC, the DIN 69901-2, the ISO 21500 and with the aid of literature and experiences of the project partners all relevant activities, sub-work packages, work packages and decommissioning phases were identified for the decommissioning of nuclear power plants. The different activities, however, were chronologically bundled as it is common for a work breakdown structure. To keep track of the overall project on the one hand and to be flexible for some optimisation on the other hand the activities are summarized in different hierarchical levels with different levels of detail.

A total number of 302 activities for the decommissioning a nuclear plant have been identified as part of the research project MogaMaR. It was ensured that regardless of the type of reactor and other factors all kinds of work can be performed by the activities in the process structure of the WBS. Because of this claim not all listed activities are relevant for each nuclear decommissioning project. On the other hand it is ensured that all activities for a complete dismantling project of a nuclear power plant are considered.

To represent the chronological order of the steps and to assign the membership to the lower level of detail at the same time a numbering is used in the WBS. The decommissioning phases, work packages, sub work packages and activities are numbered in ascending order and for each higher level of detail a further number is added. (Fig. 4)

<table>
<tr><th>Decommissioning phase</th><th>Work package</th><th>Sub work package</th><th>Activity</th></tr>
<tr><td>...</td><td>...</td><td>...</td><td>...</td></tr>
<tr><td rowspan="15">4 Dismantling of main process systems, structures and components</td><td rowspan="9">4.3 Dismantling of reactor internals</td><td rowspan="7">4.3.8 Dismantling of the lower core plate (LCP)</td><td>4.3.8.1 Transportation of the LCP beside the fuel storage pool</td></tr>
<tr><td>4.3.8.2 Dismantling of the fixings</td></tr>
<tr><td>4.3.8.3 Separation of the core shroud from the core barrel</td></tr>
<tr><td>4.3.8.4 Transportation of the core shroud into the fuel storage pool</td></tr>
<tr><td>4.3.8.5 Dismantling, cutting und removal of the core shroud</td></tr>
<tr><td>4.3.8.6 Separation of the core shroud from the LCP and transportation into the fuel storage pool</td></tr>
<tr><td>4.3.8.7 Cutting of the core shroud plate</td></tr>
<tr><td rowspan="2">4.3.9 Dismantling of the core support</td><td>4.3.9.1 Dismantling and cutting of the core support</td></tr>
<tr><td>4.3.9.2 Pack up of the pieces</td></tr>
<tr><td rowspan="6">4.4 Dismantling of reactor vessel and of other primary loop components</td><td rowspan="4">4.4.1 Dismantling of tubes</td><td>4.4.1.1 Transportation of the rod guide tubes and RSA-guide tubes into the fuel storage pool</td></tr>
<tr><td>4.4.1.2 Storage of the rod guide tubes and RSA-guide tubes in the fuel storage pool</td></tr>
<tr><td>4.4.1.3 Dismantling of rod guide tubes and RSA-guide tubes and pack up</td></tr>
<tr><td>4.4.1.4 Storage of the packed pieces in the fuel storage pool</td></tr>
<tr><td rowspan="2">4.4.2 Dismantling of the reactor vessel</td><td>4.4.2.1 Empty and clean reactor vessel</td></tr>
<tr><td>4.4.2.2 Drainage, drying and dismantling of the reactor vessel</td></tr>
<tr><td>...</td><td>...</td><td>...</td><td>...</td></tr>
</table>

Fig. 4. Cutting of the structure of the experience database

This structure is used as a list of all activities which may be relevant for decommissioning of nuclear power plants. A final arrangement of the activities in sub work packages, work packages and decommissioning phases takes place after entering the data (Fig. 5 to 7) and after the subsequent calculation of an integrated schedule, cost and resource plan by a method.

Depending on the method special data is needed. As shown in Fig. 2 these data have to be identified, procures and processed before they can be used. The data which is needed for the method described above are listed in Fig. 5 to 7. As already described the data for further calculations only can be interpreted and used by the method when the prescribed formatting of the collected data corresponds with the formatting information of the method. A proposal for a formatting for each single activity is given in Fig. 5 to 7, too.

At first for each process general data are initially recognized (Fig. 5).

Collection of general data per activity		
Data	**Formatting of the data and Explanation**	**Example**
Possible cycles	• 1 = yes; 0 = no • Any of the following processes (successor) within a cycle	„0“ or „1; 5.1.3“
Alternative processes (so-called Modes) with the same result (e.g. several methods for decontamination)	• String, if listed activity not already exists OR • Number of an activity that is already listed	„mechanical decontamination procedures“ OR „5.1.3“
Likelihood of the alternative activity (alternative modes)	decimal number	„0,5“
Validity of the activity for reactor type	BWR = Boiled water reactor PWR = Pressurized water reactor WWR = water-moderated, water-cooled reactor (placeholder for research reactor)	„PWR“
Possible scheduled interruption of an activity (date and time)	If interrupted, then enter: point in time [h], max. Time span [h] (date and time must be within the execution time of the activity)	„5; 1“
Expected duration (hours of work of a 1-shift work)	duration [h] pure working incl. Change-over times	„40“
Range / deviations of the time	Min. duration up to max. duration [h]	„30-60“
Reasons for deviations of the duration	String	„depending on the surface“
Countermeasures to prevent deviations of the durations	String or number of the activity	„Provision of another crane (on hold)“ OR „1.2.1“
Place of execution (for future change-over times and change-over costs)	String	„41-meter level“
Direct predecessor (incl. Previous relationship, e.g. the end-start or start-start)	• Only direct predecessor with number • Appended string with previous relationship (ES, EE, SS, SE) • ES = End-Start • EE = End-End • SS = Start-Start • SE = Start-End	„3.1.2ES“
Time interval between activities (e.g. waiting times to the execution of the next activity). Refers to the predecessor relationship	duration in [h]	„1“
Unforeseen / risks	String	„defective machine“
Costs (variable costs and fix costs) Unforeseen/ risks	Euro [€]	„1.000.000“
Duration/ period unforeseen	Duration in hours [h]	„100-400“
remnant (type and quantity)	String, number in [kg]	„activated concrete;5.000“
The following steps for disposal	String	„interim storage on the site“
Link of the disposal to other activities, such as if the waste / remnant of various activities is disposed together	No entry if there is no link OR With reference: Enter number of a process	„6.2.1“
Disposal costs (excluding final/ permanent disposal), for example, Costs incurred for the packaging and/ or the removal IMPORTANT: cost of final/ permanent disposal is not included	Euro [€]	„1.000.000“
Remarks	String	„ The resource of this activity is also used by activity 5.2.2. “

Fig. 5. Collection of general information for each activity in the experience database

In addition data about the resources which are used and their costs are collected (Fig. 6).

Collection of data of resources per activity		
Data	**Formatting of the data and Explanation**	**Example**
Name of the resource	String	„crane“
Number of required resource	Number	„2“
Variable costs of the resource	variable costs including overhead; All costs in Euro (excl. VAT) per hour [€ / h]	„200“
Expected duration of the resource used (including point in time of usage) concerning the activity	time in hours concerning the activity [h]; Duration in hours [h]	„20; 40“
Range/ deviations of the point in time and the duration of the usage of the resource	Min. Deviation max. Deviation of the point in time [h]; min. duration up to max. duration of the resources used in [h]	„10-30; 30-50“
Procurement of the resource (procurement lead time or consideration of development time and licensing)	0 = pure procurement (buy/ rent); 1 = new development Procurement lead time: lead time (hours [h]), which is necessary, so that the resource is available in time for use. When does the procurement has to be triggered?	„0;-72“
Alternative resources and number to achieve the same result of an activity (Modes)	string and integer	„crane;1“
Variable costs of the alternative resource (Modes)	variable costs including overhead; All costs in Euro (excl. VAT) per hour [€ / h]	„200“
Fix costs of alternative resource (Modes)	In a separate worksheet (Fig. 7)	
Required duration of alternative resource (incl. points in time for usage)	Duration in hours [h]	„20-40“
Procurement of alternative resource (procurement lead time or consideration of development time and licensing)	0 = pure procurement (buy/ rent); 1 = new development Procurement lead time: lead time (hours [h]), which is necessary, so that the resource is available in time for use. When does the procurement has to be triggered?	„0;-72“

Fig. 6. Collection of data of resources per activity in the experience database

For some activities resources are purchased or leased. In addition to the variable costs which are listed in Fig. 6 additional fix costs have to be taken into account. Sometimes these fix costs cannot be unambiguously assigned to a single activity. For this reason the fix costs are recognized in its own database by using the key "number of the activity" to link them with the other database (Fig. 7).

Collection of data concerning fix costs of the resources used		
Data	**Formatting of the data and Explanation**	**Example**
Number of the activity	allocation of resource to the relevant transactions as number	„5.2.3; 6.5.4“
Name of the resource	String	„WASS“
Number of required resources	number	„4“
Price and time of price	price in Euro [€] and date of price	„1.000.000; 01.01.2014“
Technical lifetime (for investment)	in working hours [h]	„100.000“
Usability in other projects (for investment) and percent of lifetime in the current project	1 = yes; 0 = no Percentage of lifetime in the current project as a decimal number	„1; 0,5“
Costs to assemble and disassemble (in rent)	Euro [€]	„1.000“
Fix costs of usage per hour (rent)	Euro/ hour [€/h]	„100“

Fig. 7. Collection of data concerning fix costs of the resources in the experience database

The proposed formatting of the experience database is also used by the planning method. Thus the method is able to interpret the data from the experience database. Due to the interpretation of data the method capable of conducting the activities to identify an integrated schedule, cost and resource plan.

4 Summary and Outlook

For an efficient overall planning of a project a structured planning process has to be defined. It has been shown that the planning process essentially consists of two components: At first the activities for dismantling of a nuclear facility shall be listed in a work breakdown structure. For every single activity data have to be collected and processed. After that a method calculates a project plan by using the processed data.

Previous approaches to plan the decommissioning of nuclear power plants typically used methods with deterministic approaches that take into account all activities in a fixed order and with unambiguous durations. Due to this approach and the lack of experience data from completed and ongoing decommissioning projects show significant deviations from the initial schedule and cost plans. By taking stochastic sequence elements and distributed execution times of activities into account an accurate model of a decommissioning project can be calculated. To realize this approach the methodological approaches of the PM-2 project management should be used for the planning of the decommissioning of nuclear facilities.

For the effective use of a method data is required. For the calculation of an integrated schedule, cost and resource plan data were initially determined and subsequently procured. To be able to use the data by a method a consistent formatting of the data is necessary. As part of the research project MogaMaR therefore an experience database was developed that lists all possible activities of the decommissioning of nuclear facilities in various levels of detail. Secondly each activity is listed in a consistent formatting so that the data can be used by a method to calculate an integrated schedule, cost and resource plan.

Further research of MogaMaR is concerned with the identification and application of a suitable method that meets the requirements for an integrated planning of the decommissioning of nuclear facilities. Various methods of operations research will be analysed and developed. The calculated integrated schedule, cost and resource plans will be assessed on various scenarios, on robustness and stability. Furthermore vulnerabilities which are already apparent from the data of the WBS are thoroughly investigated.

5 Acknowledgements

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