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NUCLEAR DECOMMISSIONING COSTS IN THE UNITED STATES

Joseph E. Carignan
TLG Services, Inc.

ABSTRACT

The U.S. commercial power industry has been using a proven technique of determining decommissioning cost by using a unit cost factor and an area based method. As U.S. Decommissioning projects are completed, it is now possible to obtain limited benchmark data on how well cost estimates are in line with actual costs for a project. Challenges make it almost impossible to do a one to one comparison between plants due to the fact much of the data is proprietary and also there are differences in data collection, management approaches and accounting techniques. However, the actual decommissioning costs continue to be in line with current estimates.

This presentation will provide an overview of how decommissioning cost studies are prepared along with examples of projects completed and factors affecting overall D&D costs. It will discuss some of the challenges and factors that affect overall decommissioning costs and also how they can impact overall cost and schedules.
Case studies will be presented, identifying both similarities and differences in purpose and in scope. The paper will discuss the key planning tools, for example, facility characterization assessments for radiological, hazardous and toxic contaminates.

1. INTRODUCTION

Decommissioning cost estimates, often referred to as cost studies are prepared by the owner or often a third party to assist management in determining the cost for the D&D of a facility. Cost estimates and the associated schedule are co-dependent and are an integral part of the planning process. The cost estimate can be as simple as an Excel™ spreadsheet for a small project to an elaborate process with specialized software taking months to complete such as those prepared for a large nuclear power plant. There is not a unified standard or industry approach for developing a cost estimate, however the AACE International publishes a guide making the process more consistent and provides training and certification for cost estimators. No matter which approach is taken to prepare an estimate, it is critical the product be reproducible and auditable, particularly for such a resource-intensive activity as decommissioning.

A decommissioning cost study, when prepared correctly, provides the owner with the means to make informed management decisions ensuring the decommissioning project meets the required end state in a financially responsible manner. The decommissioning study serves a number of purposes such as:

- identifies the necessary funding requirements needed to ensure sufficient funds are available at the time of decommissioning.
- provides a bases for evaluating alternative approaches to D&D and risk management.
- satisfies regulatory requirements from such agencies as the US NRC and the Financial Accounting Standards Board.
- provides a bases for detailed planning
- supports bid evaluation and monitoring contractor performance

While a well documented and prepared decommissioning cost study can be a valuable tool to the project, a poorly prepared or documented study can cause problems throughout the life of the project. If the owner has to obtain additional funding from the regulator, or from the parent company, it will result in lack of confidence in the overall project management. In addition, it could raise safety concerns if project personnel try to cut corners to try to stay within an unrealistic funding profile. In addition, public confidence could be adversely affected.

The purpose of this paper and presentation is to provide an overview of decommissioning cost estimating in the decommissioning of nuclear facilities as well as discuss results and lessons learned based on recently completed or ongoing projects.

2. DECOMMISISONING COST STUDIES

Preparation of a decommissioning cost study can be as simple as preparing an Excel™ spread sheet identifying project tasks, personnel hours, material and equipment and a schedule, to a more in depth, defensible detailed estimate using specialized software and companies that specialize in D&D cost estimating plan that uses specialized software.

One of the first things to consider in preparing a cost study is to determine the purpose. For example, a study required to support a detailed D&D plan for immediate shutdown and decommissioning will require significantly more effort than preparing a study needed for long term financial accounting.

An estimate is basically a scoping evaluation, prepared in advance of the planning and engineering required to perform the actual activities. It is not a substitute for the more detailed assessment that is required prior to commencing field work and, therefore, should be viewed as a "work in progress". Cost studies should be updated periodically as more accurate and reliable information becomes available. There are three types of estimates that are categorized as: order of magnitude, budgetary, and definitive, in accordance with an expected, increased range of accuracy. [1]

- **Order of magnitude estimate:**
  This is the least accurate of the approaches since it is prepared without the benefit of detailed engineering data. This approach is useful early in the planning process to capture the large expenditures and to bound the total project cost. However, this type of estimate is typically based upon available, historical experience. As such, it is not the preferred process upon which to establish revenue requirements.

- **Budgetary estimate:**
  This is a more accurate estimate prepared with detailed design data, including process flow diagrams, equipment location and general arrangement drawings. An inventory of plant components and structural quantities is developed from these documents and forms the basis for estimating the direct removal costs and waste stream projections. The detail available in a budgetary estimate is typically sufficient for financial modeling, and is used by many owners to justify revenue collection plans.

- **Definitive estimates:**
  These estimates are really an extension of the budgetary cost model, providing a greater level of detail. Cost centers are typically developed for discrete work activities, for integration with planning and scheduling requirements. The engineering data required for this type of estimate is generally more detailed and specific to the intended decommissioning processes. Definitive estimates provide a project management tool that can be updated over the course of the decommissioning project.

3. PREPARING THE COST STUDY:

As previously discussed, there are many factors which will affect the effort necessary to complete a study. For example, the size of the project, purpose of the estimate, and level of engineering data available are just some of the factors that will influence the overall approach and effort necessary to complete the study. Costs can be estimated in various ways from use of existing data from completed projects of similar nature, to using estimating handbooks and specialized software. However, the overall process described below is applicable for any decommissioning project. The basic approach is as follows:

- Determine Objectives and purpose for the study
- Identify Scenario(s) to be used or evaluated
- Define Assumptions
- Plant Data Collection
- Using Cost Elements, Develop Costs & Schedules

3.1. Determine Objectives and purpose for the study

As previously discussed, one of the first items for a cost estimate is to identify the objectives of the study and the reason or purpose for having it prepared. For example, it should be determined if the study is to be used for a budgetary estimate for long term financial planning, a regulatory requirement or to support prompt decommissioning. In many cases, cost studies are prepared to evaluate "what if" scenarios and as a decision analysis tool for management.

Regardless of which approach is used, the work scope must be clearly defined identifying structures and systems to be removed as well as all underground structures. If certain items, buildings or equipment are to remain in place, it should be defined early in the process. Any special considerations such as renovations or landscaping should also be identified.

3.2. Determine Alternatives and assumptions:

Assumptions should try to identify all aspects of the specific project that affect the overall costs and approach. It is recommended the various disciplines such as accounting, operations, engineering and management all participate in the process. Assumptions include but are not limited to:

- Scope of study (boundary)
- Decommissioning options such as prompt dismantlement (DECON, ENTOMB, or SAFSTOR)
- Who will manage the project? (a Decommissioning Operations Contractor (DOC) or the owner)
- How will spent fuel disposition be addressed including transportation issues, i.e. dry cask or wet storage
- Decommissioning strategy/timeline for project completion
- Funding constraints
- Identifying site specific/local community issues. Consider stakeholder involvement as well as regulatory issues

3.3. Plant Data Collection:

Data collection is based on the purpose of the study and level of effort needed. For budgetary estimates, it is often sufficient to use existing drawings, equipment lists and other documents to collect facility specific data.

For definitive estimates, the estimator has access to virtually all equipment, components and structural information to develop the estimate. In this case, personnel will be required to perform a plant walk down to identify all equipment, components and structures included in the scope of work identified. Data collected should include piping, equipment, components and structures to be removed. During this data collection phase, it is important the information collected include that information which can affect the overall efficiency of removal or have special considerations. For example, the data collected should include the component size, weight (for large components), location and access (in overhead areas requiring special equipment to reach it), if it is covered with asbestos or any other situation that would affect the overall D&D approach.

The estimator should determine the type of information needed, how it is to be collected as well as how it will be documented. If you need to know weights of large equipment, whether it is covered in asbestos or painted, then this information should be included before time and effort is spent collecting data to ensure you do not collect too much or too little information. The level of detail and the amount of information needed to support a cost study can vary significantly depending the size complexity of the project as well as the purpose of the study. However, the typical information that will be needed to develop a quality decommissioning cost study are as follows:

- Scope and assumptions well defined
- Site Characterization data
- System and Structures Inventory
- Various costs and fees including taxes, insurance and other regulatory costs
- Local area labor costs and other factors i.e. union bargaining agreements, local rental costs and various other factors

3.4. Developing and Using Unit Cost Factors

Unit cost factors assist in developing a cost study by grouping specific tasks into similar usable groups. This method is similar to the method described in the original DOE Decommissioning Handbook (1980) and again in the recently released 2004 handbook entitled "The Decommissioning Handbook"[2] . For example a UCF might be the labor, material and other costs associated with using a cutting torch to cut out a 4 foot section of 6 inch pipe. It is a safe assumption that without any worker encumbrance such as wearing protective clothing, or working on scaffolding, the specific costs to cut out this 6 inch pipe will be essentially the same for all other 6 inch piping. UCFs are readily available and can be developed based on site specific or personnel experience. Once UCFs are developed or identified, they can then be applied to the inventory of equipment and structures to estimate specific tasks for the project.

3.5. Work Difficulty Factors (WDF)

WDF are used to incorporate environmental conditions or regulatory and safety requirements for working in specific areas or on specific types of components or equipment. For example, working in a hot environment, in a confined space, or on contaminated equipment are tasks that will require special protection requirements that will adversely affect worker productively. Therefore, these WDFs are used to adjust UCFs for particular areas or conditions to more accurately reflect the actual cost associated with a particular activity. These WDFs can also be incorporated into simple projects where you may not have used UCFs but developed an estimate using other software such as Excel™ .

Examples of Work Difficulty Factors are as follows:

- Areas requiring Respiratory Protection: (10 to 50% inefficiency) – Accounts for difficulty when working with full-face respirators or air supplied masks.
- ALARA Considerations: (10 to 50% inefficiency) – Accounts for time spent for preparing to enter highly contaminated or high radiation areas including familiarization with hazards and training activities.
- Work Breaks: (8%) – Accounts for both a morning and afternoon break.
- Work Productivity Factor: This factor is used to address site specific working condition variables such as productivity differences resulting from union bargaining agreements or other limitations such as working in severe weather conditions.
- Protective Clothing required: (15 to 30% inefficiency) – Accounts for time spent in donning and removing protective clothing
- Accessibility: (10 to 20% inefficiency) – Accounts for difficulty working on scaffolding, ladders or in small or confined areas.

3.6. Using Cost Elements:

A recognized way to group cost elements to assist in preparing the cost study is to group all activities into one of three categories: 1) Activity dependent costs, 3) period dependent cost or 3)collateral costs.

3.6.1. Activity-dependent Costs

Activity-dependent (AD) costs are easiest to define because it is used to group clearly defined tasks such as decontaminating, removing packaging, transporting and disposal of a heat exchanger or other component. These activities directly correlate to the equipment and material database previously collected.

3.6.2. Period-dependent Costs

Period dependent (PD) costs are directly related to project schedule and include project management as well as support staff such as engineering, administrative, project controls, security and field supervision. This element may also include costs such as severance packages and retention costs to keep key personnel for specified periods on the project.

3.6.3. Collateral Costs (CC)

Collateral costs address those items not included in the PD and AD costs. This will include such items as insurance, taxes, permits, undistributed expenses such as health physics supplies, and one time expenses such as equipment purchase. This cost is flexible and can be used to capture site or project specific costs not addressed in other areas.

3.7. Contingency

Contingency, defined by the American Association of Cost Engineers (AACE), is "a specific provision for unforeseeable elements of cost within the defined project scope, particularly important where previous experience relating estimates and actual costs has shown that unforeseeable events that increase costs are likely to occur."

The cost elements used in a decommissioning cost estimate are typically based upon ideal conditions for performing the activities. Contingency provides a means to adjust the elements to account for delays or adverse conditions that will affect the overall cost or schedule of an activity. Experience has shown that such items such as inclement weather, tool or equipment breakdown, craft labor strikes, waste shipment problems, or disposal facility waste acceptance criteria changes, and changes in the anticipated plant shutdown conditions do occur and can adversely affect project performance. Therefore, a contingency factor is applied to more accurately determine project cost.

3.8. Scrap and Salvage

The cost estimate should also address the asset value of material that is determined to be "clean" from radioactive contamination, e.g., from scrap and/or salvage. The evaluation should be based on recent cost data obtained from scrap metal prices published daily in business newspapers and journals, and from salvage equipment companies. Examples of scrap materials would be such items as copper wire and bus bars, stainless steel plates and structural members, carbon steel and stainless pipe, carbon steel structures. Other item such as pumps, motors, tanks, valves, heat exchangers, fans, diesel engines and generators, etc., are also candidates for salvage.

3.9. Work Breakdown Structure (WBS)

The WBS is used to categorize cost elements and work activities into logical groupings that have a direct or indirect relationship to each other. The work groupings are usually related to the accounting system, or chart of accounts used for budgeting and tracking major elements of the decommissioning costs.

3.10. Integrate the Activity Cost Elements

Once cost factors have been developed, they can be applied to various systems, structures and inventory as necessary. This process can be done using a spreadsheet or specialized software that reads and compiles the UCF files. The information is often compiled vertically on a master spreadsheet with the information organized by area or system to assist in identifying specific scopes of work. Individual activities such as decontamination, removal, waste handling/processing, packaging, shipping are burial are also included horizontally, allowing the estimator to capture the various activities. Contingency can be added individually as necessary.

Once data is collected, the information can be compiled into smaller data files or spreadsheets that address specific UCFs for each item of inventory within a specific structure, system or area depending on the approach being taken. Part of the process includes evaluating the practicality of the results to ensure the number of personnel and hours expended for a particular area is reasonable. A good rule of thumb is that one crew of five working in an area requires approximately 1600 ft^2 of work area.

3.11. Preparing the Project Schedule

In preparing the project schedule, the activity dependent costs are integrated into an overall schedule by establishing estimated durations for specific activities. These UCFs also provide an estimate of the overall manpower needed to perform a specific activity. This information from the various UCF elements, when properly sequenced, will be critical inputs into the overall project schedule.

Sequencing of the project activities requires an understanding of the relationship between various activities necessary to complete the project. By sequencing activities based on a logical progression of events, it will ensure all aspects of the project are effectively integrated. It is recommended that the project activities be divided into groups of similar activities. For example, Period 1 would address all preparatory work, period 2 would address decontamination, dismantling, and license termination, while period 3 would address site restoration. Similar to any scheduling process, activities should be developed with a predecessor and corresponding successor activity to ensure the sequence is developed to ensure work is performed in the most efficient manner possible. It should be noted that many projects would involve the use of multiple or parallel work activities to reduce the overall schedule. For large or complex projects, a work breakdown structure (WBS) is used to define the cost elements and to collect and monitor project costs.

4. COMPARING REPORTED D&D COSTS

Over the last 20 years, there have been a number of nuclear power plants that have been decommissioned or are still in the process today. During this time period, decommissioning cost studies were also prepared for virtually all the U.S. power reactors in the U.S. Experience has shown it can take 6-9 years or more to complete a decommissioning of a power reactor depending on the type of decommissioning approach. During this time, many changes can occur including regulatory requirements, waste disposal costs as well as many other factors outside the control of the project. For example, after the 9-11 terrorist attack in the U.S., there has been significant costs associated with security upgrades of not only operating nuclear plants, but also for those undergoing decommissioning. In addition, as experience is gained in the industry, costs are adjusted to take into account new information. For example, in the early nineties, no one had built or licensed a dry cask storage facility so estimates to remove and store spent fuel on site were made based on limited data, often a cost was used based on a preliminary proposal from a vendor who planned on building the storage casks. As dry cask storage facilities were actually built and data became available, costs have been adjusted accordingly.

Over the years, efforts have been made to compare actual D&D costs between facilities such as power reactors as well as to compare actual D&D costs to the decommissioning cost estimates. Comparing an initial cost estimate for a power reactor prepared in the late 1980's and the actual decommissioning costs of decommissioning the facility today would be of little use. The initial cost study was probably revised 2 or 3 times to reflect industry experience, regulatory changes and changes in costs such as Low Level Waste.

Comparing decommissioning costs between nuclear power plants of similar design does not provide much useful data unless the power reactors are identical and located on the same site. Nuclear power reactors are typically located in different states, which may impose unique local or state requirements that affect the overall approach and costs. Labor rates, waste disposal rates and local community involvement also make each decommissioning project unique.

Cost studies are management and evaluation tools that evolve over time as conditions and regulations change. Even for those projects well underway, the cost study is routinely updated to reflect changes in work scope as well as conditions not under the projects control. A good example, as discussed earlier, is the security requirements that went into effect after the 9-11 terrorist attacks. Millions of dollars of security upgrades were required which were not included in the implemented cost study that was used at the start of the project.

5. WHERE DO COST ESTIMATES GO WRONG?

There are many factors that are incorporated into a cost estimate as discussed above. Those differences as well as factors listed below can affect the overall cost estimate accuracy as it relates to the "real world" These include such factors as scope changes, year of reported costs, inflation, discount rate, contingency levels, risk factor allowances, and methodological differences. Some of these are inter-related and therefore, care must be when trying to determine the reasons for differences in estimated and actual D&D costs.

5.1. Scope Changes

Experience has shown that one of the greatest factors contributing to variances in cost is the differences in scope of work in the initial estimate and the actual project work scope being performed Preliminary estimates are often prepared to compare various decommissioning options (safe storage, immediate dismantling, or entombment), as a means of evaluating and selecting a proposed approach. The assumptions used in these estimates generally define the scope of work to be performed and the schedule over which the activities will be conducted. When a recommendation is made on a given option, the assumptions of scope of work must be clearly understood, and management approval secured before approval is granted. Parametric studies may be performed of the major cost drivers to determine if the results of the recommendation change significantly and for what reason. When the given option is adopted by management, any changes made in scope of work must be reflected in a revised cost estimate to permit tracking the adequacy of the funding plan to accumulate the necessary funds to accomplish the work safely and efficiently.

5.2. Year Used to Prepare the Cost Estimate

When comparing cost estimates, it is important that the reviewer understand the year the cost estimate is based upon. The data base used for a cost estimate labor costs, materials and equipment for purchase or rental, consumables, and other collateral costs must be clearly identified and adjusted for the year of the estimate. It is difficult enough to compare estimates prepared by more than one estimator for two similar but not identical facilities, without this added disparity of reported year of costs.

5.3. Inflation

In many cases, a cost estimate is prepared years before an actual decommissioning is to take place. Therefore, inflation rates are factored into the estimate and strong affect the overall estimate. This includes not only the internal inflation factor used to update a previous year's labor rate or equipment cost data base, but also the inflation rate used to project future year of expenditure costs for an accurate projection of funding needs. For long term funding planning, the inflation rate will have a greater effect on the funding rate (annual accrual to the decommissioning fund) than any other factor in the estimate. For example, a one-half percent increase in the estimated future inflation rate (3.5%) over the actual inflation rate (3.0%) will result in a 21% higher estimated future cost over 40 years. If the current cost estimate is $500 million, the estimated future cost at the higher inflation rate would be $1.980 billion instead of $1.631 billion, a difference of $349 million. Making such projections are necessary for fund planning purposes but must be reevaluated periodically to reflect actual inflation rate experience.

5.4. Discount Rate

A similar situation exists in the estimated discount rate used to estimate the net present value of the future cost. As noted earlier, this factor needs to be reevaluated periodically to reflect recent discount rate experience.

5.5. Contingency Levels & Risk Factors

As previously discussed, contingency amounts are included to account for unforeseeable elements of cost within the defined project scope and are funds that are expected to be fully spent. The level of contingency included in the estimate reflects the level of risk the estimator and management are willing to accept..

Risk factor allowances are often included to reflect events that are not certain to occur (contrary to contingency), but may be estimated by a probability of occurrence. For example, it may be prudent to factor in costs such as anticipated loss of waste disposal availability or potential need to change waste transportation routes, etc. These factors could affect the overall costs resulting in larger than estimated increases in the total project cost. Management may want to provide additional funding to account for these probabilistic events. Estimates of risk are usually performed using probabilistic computer codes where specific risk factors are evaluated for their low, medium, and high ranges for cost over the entire spectrum of decommissioning activities. The results of such calculations could show for example that for a particular activity there is a 60 % probability that the estimated costs will not exceed 20% of the base cost (without risk). Higher probabilities will yield higher total costs.

5.6. Methodological Differences

As earlier discussion noted there are several methods for preparing cost estimates. The degree of accuracy depends on the quality of the data base of input information of the facility inventory of systems and structures, and the reliability of unit cost factors or other approaches used to apply to the inventory. It is virtually impossible to validate an estimate without the details of how the estimate was prepared. At best, a comparison can be made of the total estimated cost to the actual cost with no attempt to correlate individual cost drivers. Often, the cost and schedule tracking system used during decommissioning is not correlated to the cost estimate structure, so direct comparisons are impossible.

5.7. Selected Examples of cost Comparisons

In recent years, project managers have been conscientious in tracking costs to the estimated values on a line item basis. The early results of this effort have been remarkably good in demonstrating the accuracy of baseline estimates.

5.7.1. Maine Yankee Atomic Power Plant

Table 1 illustrates an example of the 880 MWe PWR, Maine Yankee Atomic Power Plant where actual costs were compared to estimated costs. The level of accuracy is within 8.8%. As in any estimate, individual line items of costs may be higher or lower than the estimate, but the total costs are within the range of accuracy expected for this type of project.

Table 1
Comparison of Maine Yankee 1998 Decommissioning Estimate to Actual Costs and Current Expected Cost (in 1998 dollars)

Activity	1998 Estimate, $	Actual Cost and Current Estimate, $
Staff / Staff Augmentation	116,467,257	160,255,888
Decomm. Contractors	250,367,727	283,344,667
Decomm. Settlements		(47,982,079)
Other Contract Services	28,071,200	69,859,700
Fees / Property Taxes	55,667,103	44,839,376
Insurance	12,108,827	21,503,577
Purchased Power	10,317,915	8,107,302
Rentals & Leases	1,887,970	3,502,744
Materials & Supplies	4,532,364	7,867,222
Other Expenses	8,731,875	8,917,398
Contingency	42,099,380	16,502,053
Totals	**530,251,618**	**576,717,849**

For this project a number of significant scope changes occurred which accounts for the difference in the estimate versus the actual costs. These differences include:

- Increased costs to address post-September 11 additional security measures
- Relocation of the control room twice to maintain control of operable systems
- Additional soil removed to meet changed site clearance levels from the NRC's 25 MRem/year to the State of Maine's 10 mRem/year criteria (a change that took place after the project started)
- Additional costs to remove and bury all containment building interior concrete as radioactive waste instead of demolition and use as on-site fill
- Additional engineering costs to analyze containment building demolition by ram hoe and blasting
- Increased costs for insurance post-September 11
- Additional costs to self-perform spent fuel dry storage after vendor failed to meet contract requirements

No specific accounting for the magnitude of these individual changes is available at this time. These changes in scope were not anticipated at the time the original estimate was prepared. As noted earlier contingency is an allowance for events within the defined project scope, and therefore would not be used for scope changes. However, since contingency is spent during every phase of the project the difference in contingency values reflects the amount that was actually incurred during the performance of the work accomplished.

5.7.2. Big Rock Point

Big Rock Point is a 60 MWe BWR located in Charlevoix, Michigan. Table 2 shows the comparison of estimated costs versus actual/expected costs for completion. The level of accuracy is approximately 6%, which is within the expected range for this activity.

Table 2
Comparison of Big Rock Point 2002 Decommissioning Estimate to Actual Costs and Current Expected Cost (in 2004 dollars)

Activity	2002 Estimate, $	Actual Cost and Current Estimate, $
License Termination	299,400,000	318,681,000
Spent Fuel Management	68,600,000	73,018,000
Site Restoration	27,300,000	29,058,000
Totals	**395,300,000**	**420,757,000**

In this case the contingency is included in the values listed. This case encountered several scope changes not anticipated at the start of the project, and different years of the estimate which accounts for the differences. These differences include:

- License termination activities in 2004 reflect the inflationary effect of the cost of money (approximately 3.1% per year)
- Increased spent fuel management costs incurred as the vendor encountered fabrication difficulties and delays in delivery
- Site restoration activities in 2004 reflect the inflationary effect of the cost of money

These two examples highlight the importance of accounting for scope changes for events beyond the original planned scope of work, and the impact of inflationary effects on the reported actual data.

6. CONCLUSIONS:

Decommissioning cost estimates using the Unit Cost Factor approach has proven to be a useful management and financial planning tool in the commercial nuclear industry. It has provided the nuclear industry with a means to capture the decommissioning liabilities and provide a means to monitor, track, manage and update decommissioning related costs on a routine basis.

Experience has shown the cost estimates, when properly prepared and updated, do in fact reflect the actual overall cost of a decommissioning project. In addition, much of the cost information, lessons learned and industry related experience gained over the years has been useful and effective in the planning and management of upcoming and recent decommissioning projects. However, it should be noted that in most instances, a direct comparison between decommissioning projects, even those with similar plant design, it is not feasible.

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