Decommissioning Cost Estimating Factors And Earned Value Integration

P.C. Sanford, Consultant
11221 E. Cimmarron Dr., Englewood, CO 80111

B. Skokan, Office of Project Management Oversight, EM-53
United States Department of Energy
1000 Independence Ave. SW
Washington, DC 20585

ABSTRACT

The Rocky Flats 771 Project progressed from the planning stage of decommissioning a plutonium facility, through the stripout of highly-contaminated equipment, removal of utilities and structural decontamination, and building demolition. Actual cost data was collected from the stripout activities and compared to original estimates, allowing the development of cost by equipment groupings and types and over time. Separate data was developed from the project control earned value reporting and compared with the equipment data.

The paper discusses the analysis to develop the detailed factors for the different equipment types, and the items that need to be considered during characterization of a similar facility when preparing an estimate. The factors are presented based on direct labor requirements by equipment type. The paper also includes actual support costs, and examples of fixed or one-time start-up costs.

The integration of the estimate and the earned value system used for the 771 Project is also discussed. The paper covers the development of the earned value system as well as its application to a facility to be decommissioned and an existing work breakdown structure. Lessons learned are provided, including integration with scheduling and craft supervision, measurement approaches, and verification of scope completion.

INTRODUCTION AND BACKGROUND

The data developed in this paper is based on the project that decommissioned and demolished Building 771 at the Rocky Flats Plant (Site) from 2000 through 2004. Building 771 began its 50-year existence as the facility that handled all of the plutonium weapons production. Then, as newer plutonium machining buildings were built for the expanded plutonium operations at the Site, Building 771 retained the mission to recycle plutonium from manufacturing scrap and obsolete weapons back into the weapons fabrication process and to treat plutonium-containing waste and residues. The process equipment in the building consisted of numerous gloveboxes, tanks, and piping containing many kilograms of plutonium and contaminated liquids, various waste treatment and support equipment, and an extensive process ventilation and air filtration system. There had been numerous spills and fires, and there was considerable uncertainty regarding the levels and location of contamination. Active production operations were curtailed in 1989, leaving significant quantities of plutonium in intermediate solid and solution forms that were not suitable for extended storage.

Closure for Building 771 consisted of a series of changes of management and project approach. Initially under EG&G, Inc., actions focused on reducing nuclear safety risk – risk of nuclear criticality in tanks, liquid spills, and release of a significant quantity of SNM ("material at risk") via another accident (e.g., fire). This focus resulted in reasonably detailed understanding of near-term "deactivation" activities such as plutonium solution removal from tanks and pipes and stabilization of bulk SNM, but little planning for out-year decommissioning efforts. Additional regulatory, contract (who and what scope), and performance method uncertainties also made planning for downstream activities difficult.

With the 1995 Kaiser-Hill contract, the Site began to focus more on closure, with initial decommissioning projects (laboratory Buildings 123 and 779) and a recognition that near-term activities had to be considered within their Site closure context. Building 771 began planning initial decommissioning – the removal of the highly contaminated process systems, since these systems would generally have to be removed before the less-contaminated building utilities and structure could be addressed. This planning benefited from the concurrent definition of regulatory requirements (the Rocky Flats Cleanup Agreement, 1996), overall Site closure planning, and the experience from on-going decommission, particularly for plutonium systems removal in Building 779. The previously-initiated deactivation activity to remove residual plutonium solutions from pipes was modified to include the removal of the pipe itself.

The initiation of the Kaiser-Hill Closure Project contract in 2000 required executable plans and schedules through the end of the Site closure, and removed contract scope uncertainties. During the development of the Closure Project Baseline (CPB) we recognized that labor would be a limiting resource, and that the accelerated project would require an additional workforce in addition to the Site bargaining unit employees (i.e., the United Steelworkers of America, or USW). Based on agreements to reserve USW jurisdiction for dismantlement of the more contaminated (i.e., "process") equipment, the decommissioning work was divided to allow use of a routine construction (or "Building Trades") workforce for the less-contaminated utilities, and for demolition.

The estimate approach and content evolved in parallel with the contractual phases of the project. Pre-Kaiser-Hill estimates had only the detail necessary to support the yearly budget process, with outyear estimates very conceptual in nature. Funding was only for risk reduction and support activities, and the estimate basis generally was level-of-effort with little attempt to tie the budget to detailed elements of scope. This was justifiable based on the fluidity of planning and "I'll-know-it-when-I-see-it" client direction. The Building 771 decommissioning planning beginning after 1995 used a modified version of the POWERTool estimating system. Data, principally on the process equipment to be removed, was collected using standardized work elements. This data was then combined with "work units" rates, based on Building 779 experience or bottoms-up estimates of component tasks, to yield an overall cost per "Set" of equipment to be removed. As some of the initial Sets were planned and then removed, the detailed planning and scheduling integrated the POWERTool cost estimate data to provide the earliest 771 Project earned value system.

With the development of the CPB, the estimate for the process equipment dismantlement (USW work in redefined Sets) was refined, and the work for utilities dismantlement and building demolition was planned conceptually and estimated in Building Trades work elements called "Areas". Thus most Building 771 rooms would have both a "Set" scope to remove plutonium process gloveboxes, tanks, and equipment; and an "Area" scope to remove room ventilation, cooling and fire water systems, and conduct concrete decontamination and demolition. A total project baseline budget and schedule were then developed through project completion, including remaining deactivation project support, consumables, and project waste costs. The project earned value methodology was integrated into the overall Site earned value system.

This paper is organized into three major sections. The first discusses the earned value system. The second discusses the development of the cost factors using information available from the earned value data. The third provides lessons learned from the estimating and earned value process.

EARNED VALUE SYSTEMS FOR DECOMMISSIONING

The project earned value system (1) allowed comparison of the cost of work completed against the estimate for that same work, and (2) identified cost and schedule performance at a level that could be rolled up to show overall project performance.

The Building 771 decommissioning estimate was completed significantly before the detailed work planning and scheduling, and was organized around tasks and methods that rolled in many cases to the Set level but did not distinguish pieces of equipment. Thus, all of the glovebox work in a subset, regardless of how many gloveboxes, would be included as a single cost element. As the detailed plans and working schedules were developed, many of the groupings of equipment and methods of accomplishment changed from those assumed in the estimate. Since the estimate was incorporated in the baseline, re-estimating the work would have resulted in rebaselining the project, and would have been expensive and disruptive with little value added. However, the Set level, with direct labor costs ranging from about $1 million to $10 million, was too high a level to exercise project control. To resolve this problem, the project developed its earned value reporting to take the estimate data and cast it in a form that could be reconciled with the way work was scheduled and performed.

The key to this approach was the recognition that whatever the methods assumed during the estimate development, the table of values must be equipment-based as much as possible, and be less dependent on the methods to be used (e.g., whether to erect a scaffold or use a man-lift). With earned value associated with major pieces of equipment (a tank instead of all of the tanks in a Set) or other detailed schedule element, partial value could be taken more easily. For instance, partial earned value was taken at the completion of the different stages of glovebox decommissioning – as the glovebox was decontaminated, the residual contamination fixed, the glovebox separated from ventilation, etc. Conversely, smaller pieces of equipment (e.g., pipes and valves) were grouped together, and their earned value percent complete was based on the linear feet removed divided by total linear feet. The ultimate decision was to establish the earned value element at a level that was not so high that subjective partial value judgments would distort monthly reporting, or so detailed that earned value statusing became too arduous for the additional control achieved.

The earned value system also unambiguously recorded when a specific element of work was complete. With an equipment-based approach, partial earned value was taken incrementally, but the ultimate measure of completion was when the piece of equipment was cut up, packaged as waste and the container closed. There was no room for ambiguity; when a piece of equipment was removed and/or size reduced, the whole earned value could be taken since there was no further project effort associated with that equipment. Accelerating earned value on a piece-by-piece basis tended to be self-limiting since undeservedly-positive early cost variances on that equipment were rapidly followed by negative cost variances on the residual work. That is, if the partial value taken was over-optimistic for a piece of equipment it would be self-correcting since no more earned value could be taken than the table of values figure regardless of the actual labor hours.

The original estimate for the Building 771 decommissioning activities was built around the POWERTool database. In this database, work was organized by Sets, and then by the subsets and tasks as shown in Tables I and II, and finally within “work units” such as “Set up rigging,” “Erect Scaffolding,” “Cutting Activity,” etc.

Table I. Standard POWERTool Subsets

Subset Title	Subset Scope
1. Electrical	Electrical panels, control panels, electrical boxes, conduit, motors, hoists, lights, cameras, instrumentation, transformers, SAAMs/CAMs, counting equipment, etc.
2. External Low Level Equip	Platforms, desks, cabinets, hand rails, framework, valve panels, glove bins, concrete walls, cinderblock walls, eye wash/safety shower, racks, hydraulic systems, debris, manipulators, fire suppression, sumps, sinks, decon showers, chillers, refrigeration units, etc.
3. Internal Glovebox Equip	Fulflo filters, glass pipes, metal vessels, evaporators, piping/valves, pumps, columns, flasks, hot plate, scale, chain hoists, debris, etc.
4. External Piping/ TRU Equip	Piping, criticality drains, ducts, heat exchangers, chemical pumps, small off-gas piping, vacuum traps, plena, evacuator/pull pump, etc.
5. Tanks	Tanks, Raschig rings, sight glasses, tank supports, etc.
6. Glovebox/ Misc Equip	Gloveboxes, B-boxes, scrubbers, pedestals, pneumatic transfer piping, large off-gas piping, etc.

The Subset and Task matrix allowed estimate roll-ups to identify costs by media (all tank activities are Subtask 5) and “work type,” both of which turned out to be unnecessary information from an earned value standpoint. All of the glovebox work in a Set, regardless of how many gloveboxes there were, would be included as a single cost element. An example of this breakdown is shown the Table of Values in Appendix 1.

Table II. Standard POWERTool Tasks

Task A	Initial Characterization
Task B	Additional Technical Support
Task C	Internal Equipment Disassembly
Task D	Internal Decontamination to Stabilize/Reduce Hazards
Task E	Internal Decontamination to Convert Waste Form
Task F	External Equipment Disconnection and Removal
Task G	Size Reduction In-Situ
Task H	Size Reduction Facility
Task I	Waste Packaging

During the detailed planning and scheduling of the work, the subset/work units from the estimate were recast as costs per piece of equipment in a way that could be related to schedule element. For example, all glovebox costs were pro-rated among the Set gloveboxes based on the ratios of the respective glovebox surface areas. Thus, all of the costs still rolled up to the same Set cost, and all Sets retained a common estimate basis. An example of the Equipment Percent Complete table is shown in Appendix 2, which covered the same scope as the table in Appendix 1. These Equipment Percent Complete sheets were updated at weekly scheduling and progress reporting meetings attended by craft foreman, line management, and project controls personnel. The percent completes (including partial value by piece of equipment) were then applied to the Table of Values to give the Set earned value in dollars.

The final breakout of the estimate data was during the development of the Building Trades scope. The definition of the Building Trades work occurred during the development of the Closure Project Baseline. Prior to that, the cost estimate to remove most of the non-process/utility equipment, decontaminate building walls, and demolish the building structure was conceptual. The Closure Project Baseline assumed that the Building Trades work would be subcontracted, and developed estimate bases to support that assumption. Bottoms-up estimates were developed for surface decontamination, removal of contaminated non-structural partitions, and the physical building demolition. Elements of the POWERTool estimates that covered non-process equipment were removed from the Set scope and included in the Area scope.

COST FACTORS

Developing a detailed estimate requires taking a scope of work, and begins by dividing it into small enough tasks or work elements that will allow resources and costs to be confidently determined. The estimate is impacted by the methods used to execute the work, the way the scope is defined and divided in to work elements, and cost and resource factors that are available to apply to these work elements that accurately reflect the resources necessary to accomplish the work. The sources for factors for the Building 771 Project estimate were largely-anecdotal input from earlier projects, bottoms-up estimates of tasks based on individual worker actions, and general construction references with productivity factors. There was little quantitative data available for the original estimate that related the equipment to be removed to the removal labor and cost. The purpose of the work described in the remainder of this paper is to provide improved cost factors derived from actual 771 Project data.

We had to work within several constraints to capture the actual costs and develop factors that related labor and cost to generic equipment metrics that might be applicable to future decommissioning work. As the project progressed, management attention was on safe and efficient project execution, not capturing cost data for future estimating. Activities such as time studies to quantify and capture worker productivity by equipment element were given little priority. However, the project control system used by management to track progress and cost/schedule variances provided comparisons of estimated and actual costs. The challenge was to tease out equipment cost factors from this project control data designed to be summarized at a higher level.

The actual costs were collected by charge code in the "Joshua" accounting database, providing weekly reporting of direct labor costs (and hours), consumable cost, and subcontracted costs. The charge codes separated costs by Set and by other (indirect) cost accounts (e.g., project management, surveillance and maintenance, waste management, etc.). Within the Set cost accounts, direct worker-recorded labor hours were further differentiated within six different "media-based" cost codes – in-room glovebox work (-301), piping removal (-302), in-room tank removal (-303), duct removal (-304), "balance" (-305), and "size reduction" (-306). "Balance" included the work of removing those non-process items that were not left for the "Area" scope – electrical control panels, conduit, equipment – as necessary for access to process areas and systems. "Size reduction" included the work of cutting up sections of TRU equipment (typically gloveboxes and tanks) in dedicated size reduction chambers to fit in waste boxes. These size reduction or "inner tent chambers" were located at remote locations in Building 771 and were operated by a dedicated size reduction crew. The cost codes did not differentiate by individual piece of equipment; i.e., the labor for work on all gloveboxes in a Set was charged to the same charge number.

Although the reporting of the direct labor hours and costs by Set appears accurate, to be useful an estimating factor needs to apply at the equipment level to allow for Set differences. Initial efforts to develop factors using the "media" charge number hours and "metrics" for equipment (i.e., cubic feet of gloveboxes, linear feet of pipe, etc.) yielded factors that differed widely between Sets for the same item. Much of this is believed to be related to worker time-charging compliance, which appeared to improve as the project progressed. A different approach, using multiple regression techniques applied to overall Set data[1], yielded reasonable factors with adequate correlation coefficients, which would probably be suitable for conceptual estimates where little information is available to differentiate equipment. A third approach attempted to combine the data available in the project's earned value system to differentiate between the individual pieces of equipment for a single Set. This approach was intended to provide data that could be used for detailed estimates. This approach has been improved and expanded to additional Sets, and is discussed further in this paper.

The purpose of the project earned value system as discussed in the previous section was to allow comparison of the cost of work completed with the cost that had been estimated for that same work, and identify cost and schedule performance at a Set level that can be rolled up to show overall project performance. The system was based on the original POWERTool estimate that broke Sets into "subsets" and then into "work units." Thus, all of the glovebox work in a subset, regardless of how many gloveboxes, was included as a single cost element (Appendix 1). During the detailed planning and scheduling of the work, the subset/work units were recast as costs per piece of equipment in a way that could be related to schedule element (Attachment 2). As a result, as a piece of equipment was removed and/or size reduced, the earned value could be taken. The earned value reports were updated weekly for the duration of the project.

The direct labor and most project costs were reported on a weekly basis, and the earned value and schedule data were available on a weekly basis. We reasoned that if we could achieve satisfactory correlation between the actual-cost reporting and the earned value reporting we could, in principle, be able to identify the effort required to decommission each piece of equipment. In other words, if the only earned value taken for the week was for the decommissioning of a specific glovebox then the hours worked that week could all be attributed to that glovebox. Several ways could then be used to group the individual pieces of equipment into types (e.g., pencil tanks vs. raschig ring tanks) or activities (e.g., raschig ring removal).

There were several practical problems with this approach. First, the earned value was taken as a particular piece of work was completed, not necessarily as it was done, although most of the time partial credit was taken. Thus, week by week correlation was not perfect. Also, if more than one element was being worked on in a given week then the labor ratios between elements are assumed to be proportional to the earned value ratios. This will only be exactly correct if the work units in the original estimate were correct. These problems would result in unacceptable random scatter if the method was used to derive the cost of an individual piece of equipment. We were able to compensate for this error by averaging the cost of similar

[1] "Decommissioning Unit Cost Data," Sanford, P.C., Stevens, J.L., and Brandt, R., WM'02 Proceedings

pieces of equipment first across a Set, and then between Sets. There were also ways to arrange the data and to apply the media-specific charge number to reduce the impacts of these problems. Table III shows the result of this approach for the Set 36 Raschig Ring Tanks. Using this approach, direct labor values were developed for the following equipment types, as shown in Table IV and Table V.

Table IV. Labor Factors by Glovebox Category (Direct Labor Hours per metric)

Category	No. Entries	Hours	Metric Unit	Metric Value	Hours Per Metric Unit
Glovebox Internal Equipment Removal					
Crit Drain	47	1,258	Each	47	26.78
FulFlo Filter Assembly	32	2,063	Wt (Lbs)	3,985	0.52
Furnace	4	189	Wt (Lbs)	400	0.47
GB Internal Debris	34	2,267	Wt (Lbs)	4,261	0.53
GB Internal Miscellaneous	65	5,374	Wt (Lbs)	7,940	0.68
GB Internal Piping/Valves	27	3,307	Length (LF)	1,971	1.68
GB Internal Pump	25	1,027	Wt (Lbs)	3,125	0.33
GB Internal Tank	4	462	Wt (Lbs)	600	0.77
Glass Flask	1	20	Wt (Lbs)	20	1.02
Glass Pipes	20	1,154	Wt (Lbs)	3,150	0.37
Pump Box	2	299	Surf Area (SF)	62	4.82
Vacuum Pump	2	46	Wt (Lbs)	600	0.08
Glovebox Dismantlement					
In Service	38	7,477	Surf Area (SF)	11,002	0.68
Decon-Fix	38	1,995	Surf Area (SF)	11,002	0.18
Separate	38	16,463	Surf Area (SF)	11,002	1.50
Size Reduce ITC	11	18,176	Surf Area (SF)	4,438	4.10
Size Reduce SCO	27	12,509	Surf Area (SF)	6,564	1.91
Support Removal	38	1,737	Surf Area (SF)	11,002	0.16
Recover Area	38	4,996	Surf Area (SF)	11,002	0.45
Glovebox Summary Cost					
Glovebox Inclusive	40	81,533	Surf Area (SF)	11,028	7.39

Table IV lists the different categories, the number of items or entries on which the labor factor is based, the total number of hours for all category work, the unit or metric which was used for correlation, the metric total for the category, and the factor in direct labor hours per unit/metric. The first section lists the individual types of equipment that might have to be removed from the inside or (in the case of the glovebox overflow) exterior of the glovebox. The items under Glovebox Dismantlement section are those activities necessary to remove the glovebox itself – placing it in-service (by replacing gloves, adjusting ventilation, etc.), decontaminating the interior after internal equipment has been removed, separating the glovebox for either subsequent size reduction or final packaging for disposal as a Surface Contaminated Object, and removal of glovebox supports and are recovery after the glovebox has been removed. The final section, Glovebox Summary Cost, provides a total average rate for all activities associated with glovebox decommissioning. Appendix 3 provides additional description of the categories.

Table III. Set 36 Detailed Tank Breakout

		Metric	Dollars	Calendar Week (2002)											Hours	Hours
Item	Category	Cubic Feet	Total EV	1/13	1/20	1/27	2/3	2/10	2/17	2/24	3/3	3/10	3/17	3/24	Total	Per CF
Tank 1013 - Raschig Ring	Tank - R Ring	21.68	7,989			5	8	9	15			26	28	15	106	4.88
Tank 1014 - Raschig Ring	Tank - R Ring	21.68	7,989			5	8	9	15		9	26	28	12	112	5.15
Tank 1022 - Raschig Ring	Tank - R Ring	26.08	11,836			7	12	13	22			38	41	23	157	6.01
Tank 1023 - Raschig Ring	Tank - R Ring	26.08	11,836			7	12	13	22		22	38	41	15	171	6.56
Tank 1024 - Raschig Ring	Tank - R Ring	26.08	11,836			7	12	13	22	28	66	38	27		214	8.20
Tank 1007 - Raschig Ring	Tank - R Ring	15.71	7,839			12	16	18	24	37	29	17			153	9.72
Tank 1008 - Raschig Ring	Tank - R Ring	26.08	13,065			20	27	59	122	62					289	11.09
Tank 1050 - Raschig Ring	Tank - R Ring	5.30	3,920	6	8	18	12	13							73	13.72
Tank 1053 - Raschig Ring	Tank - R Ring	5.30	4,355	28	50	13									118	22.34

Notes:
1) These values are for individual tanks in Set 36 only. Overall rates are given in Table V.
2) Table III provides the resultant hours of craft work for the listed tanks. The earned value and total Set hours worked for each week that supports the overall calculations are not shown.

Deleted: Tank 1053 - Raschig Ring
Deleted: Tank – R Ring
Deleted: Tank 1050 - Raschig Ring
Deleted: Tank – R Ring
Deleted: Tank 1013 - Raschig Ring
Deleted: Tank – R Ring
Deleted: Tank 1014 - Raschig Ring
Deleted: Tank 1022 - Raschig Ring
Deleted: Tank 1023 - Raschig Ring
Deleted: Tank 1007 - Raschig Ring
Deleted: Tank 1024 - Raschig Ring
Deleted: Tank 1008 - Raschig Ring

Table V. Labor Factors by Non-Glovebox Equipment Category (Direct Labor Hours per metric)

Category	No. Entries	Hours	Metric Unit	Metric Value	Hours Per Metric Unit
External Piping (TRU-Contaminated)					
Miscellaneous External	18	520	Wt (Lbs)	3,400	0.15
Piping/Valves	40	5,517	Length (LF)	22,063	0.25
Vacuum Trap	24	736	Each	24	30.68
Low-Level Contaminated Materials					
Control Panel	33	976	Each	51	19.07
Electric Motor	28	510	Wt (Lbs)	3,215	0.16
Electrical Conduit	23	3,627	Length (LF)	17,418	0.21
External Equip	121	3,074	Wt (Lbs)	35,005	0.09
Glovebox Overheat	1	139	Volume (CF)	1,434	0.10
Tanks					
Remove Raschig Rings	3	336	Volume (CF)	143	2.35
Tank - Annular	26	4,810	Volume (CF)	1,818	2.65
Tank - Annular-Part SR	7	2,518	Volume (CF)	501	5.03
Tank - Annular-SR	7	2,420	Volume (CF)	594	4.08
Tank - Pencil	40	901	Volume (CF)	48	18.83
Tank - Pencil-SR	17	1,550	Volume (CF)	23	67.11
Tank - Raschig Ring	44	12,510	Volume (CF)	1,506	8.31
Tank - Raschig Ring-SR	6	1,965	Volume (CF)	277	7.08

The data in Table V is given in the same format as that in Table IV. The first section provides information on removal of process piping, the second on dismantling non-process equipment in process areas, and the third decommissioning of different types of tankage associated with concentrated plutonium solutions that are designed to prevent nuclear criticality. Appendix 3 provides additional description of the categories.

The data in Table IV and Table V represents all USW decommissioning work for three of the largest building Sets – Set 61, Set 66, and Set 36 – a large enough sample to be representative of all of this type of work within the building. These Sets include approximately one third of the glovebox and tank process equipment decommissioning in Building 771 (including the most difficult areas – Rooms 114, 149, and 146). They include approximately one quarter of the USW work in the building, with the remaining USW work consisting of the decommissioning of process filter plenums and duct and removal of equipment associated with the low-level waste treatment in Building 774. The activities addressed in these tables are the core critical path decommissioning activities in a plutonium closure project. In other major DOE sites, a large portion of the decommissioning costs of plutonium facilities will be made up of gloveboxes, ventilation, tank, and piping costs, so the use of the above factors should allow improved accuracy for estimates of costs and schedules for these facilities.

Several qualifiers are provided for the use of this data. The labor factors include only direct labor hours for decommissioning work. This includes the work crew of D&D workers, health physics technicians, and direct supervisors – all of the USW labor. Labor cost for these Sets, including fringes, was about $43.80 in 2002-year dollars, and the USW labor cost was about 65% of the total cost for the Set. The remaining 35% of the cost was mostly directly charged subcontracted labor, typically engineering or technical support not present at the Set location during decommissioning operations. All of these costs are part of Cost Account 1CAD, Decommissioning (Sets) costs shown in Table VI.

Table VI shows all of the costs for decommissioning Building 771 between 2000 and 2004 and allows the direct Set dismantlement hours and costs to be placed in the context of overall project costs. Costs for support staff, consumables, rentals, waste handling, engineering and planning, etc. that are not addressed under the direct Set costs are included in Cost Account 1CAE. Project management, facility surveillance and maintenance, and deactivation (e.g., draining of liquids from tanks and pipes) are included under their own Cost Accounts. Cost multipliers may be developed from the values in this table to estimate the management and support requirements for a plutonium facility decommissioning project.

Table VI. Building 771 Project Cost Breakout (nominal 2002 dollars)

Cost Account	Building 771 Project Cost Account Description	Hours	Dollars	Percent of Total Hours	Percent of Total Dollars
1CAA	Project Management	49,483	4,991,195	2.6%	2.2%
1CAB	Facility Surveillance & Maint.	549,852	40,982,756	28.5%	17.8%
1CAC	Deactivation	230,523	14,965,448	11.9%	6.5%
1CAD	Decommissioning (Sets)	513,116	35,526,476	26.6%	15.4%
1CAD	Decommissioning (Areas)	164,728	68,605,645	8.5%	29.8%
1CAE	Support Services	424,583	64,915,729	22.0%	28.2%
Total		1,932,285	229,987,249	100.0%	100.0%

Table VII provides a simple example of the use of factors to develop the cost for removing a glovebox with 200 square feet of external surface area containing a 300-pound furnace; the furnace is removed and the glovebox is then decontaminated and disposed of as a low-level waste Surface Contaminated Object. (SCO).

Table VII. Example Use of Factors

	Factor	Metric	Hours/$	Comments
Furnace	0.47	300	141	Hours spent to remove furnace (internal equipment)
In Service	0.68	200	136	Hours to make glovebox ready for work
Decon-Fix	0.18	200	36	Hours to decontaminate and fix interior surfaces
Separate	1.5	200	300	Hours to separate the glovebox from other sections
Size Reduce SCO*	1.91	200	382	Hours to address final handling, wrapping and packaging in a shipping container
Support Removal	0.16	200	32	Hours to remove glovebox stand
Recover Area	0.45	200	90	Hours to remove tents, etc.
Total Labor hours			1,117	Total hours by D&D work crew
Burdened rate	$/hr		43.8	
Total Labor Cost			$48,925	
Non-Labor Cost Factor		25.9%	$12,684	
Total Direct Cost			$61,609	
Support Services Factor		91.4%	$44,699	Apportioned support cost; biased to reflect increased support requirements for glovebox work
S&M Factor		35.5%	$15,873	Apportioned cost so maintain safety envelope
PM Factor		2.2%	$352	Apportioned project management cost
Total cost to remove glovebox			$184,141	

*Note: A glovebox cannot be both size-reduced in an Inner Tent Chamber and dispositioned as SCO; it is either one or the other.

LESSONS LEARNED

A number of lessons learned have been identified from the overall estimating factor development and earned value process.

1) The earned value approach that was used for Building 771 is generally applicable to other facilities to be decommissioned. In some cases the planning will be at the conceptual level. In that case the development of “Sets” that map to physical areas (rooms or portions of rooms) and specific equipment is important, based on the recognition that work will generally proceed by area (not chasing “systems” all across a facility). More often, there will be an existing work breakdown structure that has divided the work scope, and an existing estimate. In the event that an estimate is believed to be credible, the development of the Table of Values during the detailed planning will allow specific elements to be validated. The exact format of the 771 Project Equipment Percent Complete and Table of Values spreadsheets were an artifact of the estimating history and could be streamlined for a new project.

2) The integration of the earned value assessment with regular scheduling meetings makes the first-line supervision aware of the direct impact of their work on the project progress reports. Also, reporting at this level provides a basis that will withstand audits and management reviews in justifying progress and variances.

3) During the walk-downs and item take-offs of Building 771 that preceded the estimate, work was defined in terms of actions. For instance, the labor hours identified for glovebox, tank, or duct to be size-reduced was determined by the “length of cut” to turn the equipment into pieces that could be laid into a standard waste box. Every glovebox, tank, or duct was examined and given a “length of cut” metric. This turned out to be of little value, in that it was not the way craftsmen did the work and added an unnecessary level of complexity. When the work was distributed into the earned value elements, the cost of the glovebox (or tank) removal was apportioned between gloveboxes based on the individual glovebox (or tank) surface area. The lesson from this was that a better estimate approach would have been to use a surface area factor in the initial estimate. Glovebox surface area also correlated better with glovebox removal labor than glovebox volume.

4) A lesson learned from the walk-down/take-off data gathering was to better distinguish between systems, particularly “process” and “utility,” based on how the materials would need to be handled during removal (the “process” materials were transuranic waste unless decontaminated). This was initially useful in segregating Set and Area scope, and also useful in assessing whether equipment needed to be size reduced (in a dedicated size reduction facility, at considerable expense) or could be removed in larger pieces and disposed of as low-level waste.

5) The categories in Table IV may be applied to identifying items that need to be considered during walkdown/data collection in a Plutonium facility. Initial data should be collected on individual equipment at the level that will be used in scheduling, or perhaps one level below. In the case of plutonium processes, that has typically been gloveboxes, tanks, duct sections, filter plenums, and similar items. For other items, such as piping, conduit, electrical panels, structural steel, utility piping and the like, earned value will probably be taken on an area basis, which may range from the size of the room down to a few hundred square feet. The takeoffs should still be on the basis of some metric (e.g., pieces of equipment or linear feet) with those areas. If as-built drawings are accurate they may be used for both as a basis for estimate take-offs and to record the earned value for piping removal (or removal of other materials where earned value credit is taken on a metric basis, such as duct).

6) There may be some methodology-dependent elements required for both earned value and the estimate development. In Building 771 we had seven activities associated with each glovebox – Place Glovebox In Service, Internal Equipment Removal, Decontaminate-Fix, Separate, Size Reduce, Support Removal, and Recover Area. As long as the ultimate basis is a single piece of equipment (i.e., not all of the gloveboxes or tanks in a Set) the take-offs can be readily adjusted during the detailed planning.

SUMMARY

The work of decommissioning the Rocky Flats 771 Project process equipment was completed in 2003. Early in the planning process, we had difficulty in identifying credible data and implementing processes for estimating and controlling this work. As the project progressed, we were able to collect actual data on the costs of removing plutonium contaminated equipment from various areas over the life of this work and associate those costs with individual pieces of equipment. We also were able to develop and test out a system for measuring the earned value of a decommissioning project based on an evolving estimate. These were elements that would have been useful to us in our early planning process, and we would expect that they would find application elsewhere as the DOE weapons complex and some commercial nuclear facilities move towards closure.

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For additional information or comments please contact us at sanfordp@hotmail.com.

Appendix 1

LineID	LineTitle	Budget	Weighted Value	Percent Complete	Earned Value %	Earned Value $
4X36C1F01	Isolation of All Systems (Electrical)	$4,422.55	0.74%	100.00%	0.74%	$4,422.55
4X36C1F03	Electrical (Rmvl of Conduit & Components)	$49,726.22	8.33%	100.00%	8.33%	$49,726.22
4X36C1F04	Setup Rigging (Electrical)	$39.46	0.01%	100.00%	0.01%	$39.46
4X36C1F05	Erect Scaffolding (Electrical)	$604.86	0.10%	100.00%	0.10%	$604.86
4X36C2G04	Erect Scaffolding (Ext LL Equipment)	$604.86	0.10%	100.00%	0.10%	$604.86
4X36C2G05	Setup Rigging (Ext LL Equipment)	$78.92	0.01%	100.00%	0.01%	$78.92
4X36C2G06	Cutting Activity (Ext LL Equipment)	$68,946.92	11.55%	100.00%	11.55%	$68,946.92
4X36C2G07	Initial Wrapping/Packaging (Ext LL Equipment)	$7,490.36	1.26%	100.00%	1.26%	$7,490.36
4X36C2G08	In Progress Area Decon (Ext LL Equipment)	$1,632.13	0.27%	100.00%	0.27%	$1,632.13
4X36C2G09	Structural Support Removal (Ext LL Equipment)	$3,254.87	0.55%	100.00%	0.55%	$3,254.87
4X36C3C04	Component Size Reduction (Int GB Equipment)	$6,165.03	1.03%	100.00%	1.03%	$6,165.03
4X36C3C06	Debris Prep and Bagout (Int GB Equipment)	$2,905.15	0.49%	100.00%	0.49%	$2,905.15
4X36C3F01	Isolation of All Systems (GB Overheat)	$1,400.36	0.23%	100.00%	0.23%	$1,400.36
4X36C4F01	Isolation of All Systems (Ext Pipe/TRU Equipment)	$17,754.10	2.98%	100.00%	2.98%	$17,754.10
4X36C4F02	Process Piping (Ext Pipe/TRU Equipment)	$86,753.79	14.54%	100.00%	14.54%	$86,753.79
4X36C4F04	Setup Rigging (Ext Pipe/TRU Equipment)	$39.46	0.01%	100.00%	0.01%	$39.46
4X36C4F05	Erect Scaffolding (Ext Pipe/TRU Equipment)	$604.86	0.10%	100.00%	0.10%	$604.86
4X36C5C07	Remove Raschig Rings (GB/Misc Equipment)	$1,000.18	0.17%	100.00%	0.17%	$1,000.18
4X36C5F02	Process Piping (Tanks/Raschig Rings)	$2,958.83	0.50%	100.00%	0.50%	$2,958.83
4X36C5F08	Sleeves (Tanks/Raschig Rings)	$7,348.54	1.23%	100.00%	1.23%	$7,348.54
4X36C5G02	Erect SSCs (Tanks/Raschig Rings)	$5,480.48	0.92%	100.00%	0.92%	$5,480.48
4X36C5G04	Erect Scaffolding (Tanks/Raschig Rings)	$604.86	0.10%	100.00%	0.10%	$604.86
4X36C5G05	Setup Rigging (Tanks/Raschig Rings)	$39.46	0.01%	100.00%	0.01%	$39.46
4X36C5G07	Initial Wrapping/Packaging (Tanks/Raschig Rings)	$183.48	0.03%	100.00%	0.03%	$183.48
4X36C5G08	In Progress Area Decon (Tanks/Raschig Rings)	$1,042.66	0.17%	100.00%	0.17%	$1,042.66
4X36C5G09	Structural Support Removal (Tanks/Raschig Rings)	$314.54	0.05%	100.00%	0.05%	$314.54
4X36C5G10	Recover Area (Tanks/Raschig Rings)	$2,580.49	0.43%	100.00%	0.43%	$2,580.49
4X36C6C01	Cert/Prep Glovebox For Use (GB/Misc Equipment)	$2,053.80	0.34%	100.00%	0.34%	$2,053.80
4X36C6C03	Glove Replacements (GB/Misc Equipment)	$3,119.56	0.52%	100.00%	0.52%	$3,119.56
4X36C6D01	Apply Fixatives (GB/Misc Equipment)	$483.34	0.08%	100.00%	0.08%	$483.34
4X36C6D02	Wipedowns (GB/Misc Equipment)	$1,008.97	0.17%	100.00%	0.17%	$1,008.97
4X36C6F01	Isolation of All Systems (GB/Misc Equipment)	$18,322.10	3.07%	100.00%	3.07%	$18,322.10
4X36C6F02	Process Piping (GB/Misc Equipment)	$1,479.41	0.25%	100.00%	0.25%	$1,479.41
4X36C6F08	Sleeves (GB/Misc Equipment)	$3,391.43	0.57%	100.00%	0.57%	$3,391.43
4X36C6G02	Erect SSCs (GB/Misc Equipment)	$11,508.94	1.93%	100.00%	1.93%	$11,508.94
4X36C6G04	Erect Scaffolding (GB/Misc Equipment)	$604.86	0.10%	100.00%	0.10%	$604.86
4X36C6G05	Setup Rigging (GB/Misc Equipment)	$78.92	0.01%	100.00%	0.01%	$78.92
4X36C6G06	Cutting Activity (GB/Misc Equipment)	$45,536.92	7.63%	100.00%	7.63%	$45,536.92
4X36C6G07	Initial Wrapping/Packaging (GB/Misc Equipment)	$2,752.42	0.46%	100.00%	0.46%	$2,752.42
4X36C6G08	In Progress Area Decon (GB/Misc Equipment)	$2,085.32	0.35%	100.00%	0.35%	$2,085.32
4X36C6G09	Structural Support Removal (GB/Misc Equipment)	$3,743.01	0.63%	100.00%	0.63%	$3,743.01
4X36C6G10	Recover Area (GB/Misc Equipment)	$5,721.72	0.96%	100.00%	0.96%	$5,721.72
	Subtotal Execution	**$375,868.14**	**62.98%**		**62.98%**	**$375,868.14**
4X36J01	Set 36 Support Services	$220,896.05	37.02%	100.00%	37.02%	$220,896.05
	Subtotal Waste/Support Services	**$220,896.05**	**37.02%**		**37.02%**	**$220,896.05**
	Total Execution	**$596,764.19**	**100.00%**		**100.00%**	**$596,764.19**

Table of Values for Set 36, Subset C only.

Appendix 2

	Weight	% Complete	Earned %	Location
Electrical				
Electrical conduit, disconnects	76.00%	100.00%	76.00%	Entire Set
Control Panel	6.00%	100.00%	6.00%	MT-2 West
Control Panel	6.00%	100.00%	6.00%	Rm 146 N of Pump Box
Electric Motor	6.00%	100.00%	6.00%	Pump Box North
Electric Motor	6.00%	100.00%	6.00%	Pump Box South
	100.00%		**100.00%**	
External Low Level Equip				
Glovebox MT-8 (cold)	Removed	Prior to Rebaseline		
Glass Pipe	Removed	Prior to Rebaseline		MT-8 North End
Glass Pipe	Removed	Prior to Rebaseline		MT-8 South End
Scale	10.00%	100.00%	10.00%	MT-2 North End
Chiller Unit	40.00%	100.00%	40.00%	Rm 146 SE Corner
Tank 1071	20.00%	100.00%	20.00%	Rm 146 SE Corner
Tank 1072	20.00%	100.00%	20.00%	Rm 146 SE Corner
Rack	10.00%	100.00%	10.00%	Rm 146 SE Corner
	100.00%		**100.00%**	
Internal/Glovebox Equip				
Piping/Valves	Removed	Prior to Rebaseline		MT-8
Debris	Removed	Prior to Rebaseline		MT-8
Piping/Valves	60.00%	100.00%	60.00%	MT-2
Debris	40.00%	100.00%	40.00%	MT-2
	100.00%		**100.00%**	
External Piping/TRU Equip				
Piping/Valves	Removed	Prior to Rebaseline		MT-8
Vac Trap 1057	Removed	Prior to Rebaseline		East of MT-8
Vac Trap 1262	Removed	Prior to Rebaseline		North of MT-8
Crit Drain	Removed	Prior to Rebaseline		MT-8
Piping/Valves	25.00%	100.00%	25.00%	Entire Set
Piping/Valves	12.50%	100.00%	12.50%	MT-2
Vac Trap 1052	2.50%	100.00%	2.50%	East of South Pump Box
Vac Trap 1055	2.50%	100.00%	2.50%	East of North Pump Box
Vac Trap 1059	2.50%	100.00%	2.50%	North of North Pump Box
Vac Trap 1061	2.50%	100.00%	2.50%	West of North Pump Box
Vent Trap 1051	2.50%	100.00%	2.50%	East of Tank 1050
Vent Trap 1054	2.50%	100.00%	2.50%	North of Tank 1050
Crit Drain	2.50%	100.00%	2.50%	Pump Box North
Crit Drain	2.50%	100.00%	2.50%	Pump Box South
Crit Drain	2.50%	100.00%	2.50%	MT-2 Center
Heat Exchanger	10.00%	100.00%	10.00%	East of South Pump Box
Heat Exchanger	10.00%	100.00%	10.00%	East of North Pump Box
Heat Exchanger	10.00%	100.00%	10.00%	Rm 146 SE Corner
Heat Exchanger	10.00%	100.00%	10.00%	Rm 146 SE Corner
	100.00%		**100.00%**	
Tanks/Raschig Rings				
Tank 1050 - Raschig Ring	19.07%	100.00%	19.07%	North of South Pump Box
Tank 1053 - Raschig Ring	21.19%	100.00%	21.19%	East of North Pump Box
Tank 1069 (Vacuum Header)	52.97%	100.00%	52.97%	Rm 146 East of MT-2
Tank 1073	6.77%	100.00%	6.77%	Rm 146 SE Corner
	100.00%		**100.00%**	
Gloveboxes/Misc Equip				
Glovebox/ Exhaust Piping	73.20%	100.00%	73.20%	MT-2
Pump Box - North	11.76%	100.00%	11.76%	NE of MT-2
Pump Box - South	11.76%	100.00%	11.76%	SE of MT-2
Vacuum Pump	1.63%	100.00%	1.63%	North Pump Box
Vacuum Pump	1.63%	100.00%	1.63%	South Pump Box
	100.00%		**100.00%**	

Equipment Percent Complete Table, Set 36, Subset C only

Appendix 3

Category	Description
Glovebox Internal Equipment Removal	
Criticality Drain	Criticality drains are pipes with liquid traps that ensure that liquid levels in gloveboxes do not become deep enough to allow a criticality to occur.
FulFlo Filter Assembly	Cartridge filters used to remove solids from plutonium nitrated solutions during ion exchange or other liquid processing, along with associated piping.
Furnace	Muffle furnaces or other electric furnaces used for drying or fusing materials.
GB Internal Debris	Miscellaneous materials that require minimal size reduction and bagging out of a glovebox.
GB Int Miscellaneous	Equipment that may require size reduction inside the glovebox before it can be bagged out.
GB Int Piping/Valves	Interior piping that must be sized reduced prior to removal form the glovebox
GB Int Pump	Pumps
GB Int Tank	Tanks that must be disassembled and may require size reduction
Glass Flask	Unconnected flasks, similar to debris.
Glass Pipes	4'' or 6"diameter glass pipes for tanks (so operators can see liquid levels) or ion exchange columns
Pump Box	Small glovebox used for vacuum pump
Vacuum Pump	Vacuum pump; typically larger than liquid pumps; associated with pump box
Glovebox Dismantlement	
In Service	Place glovebox in condition for use; may include installation of gloves, authorization basis activities, changing glovebox exhaust filters, etc.
Decon-Fix	After removal of all interior materials, decontaminated walls, survey to determine contamination levels and if SCO disposal is an option. After formal SCO determination, paint walls to prevent further spread of residual contamination during handling or size reduction.
Separate	Remove from ventilation and separate (plastic sleeve) from other gloveboxes in group as necessary.
Size Reduce ITC	Size reduction for packaging into a TRU disposal container at special size reduction facility.
Size Reduce SCO	Final packaging to place in cargo container for LLW disposal; may include removal of appurtenances that are TRU to render the remainder of the glovebox SCO.
Support Removal	Remove glovebox legs and other structural supports.
Recover Area	Remove any other miscellaneous and demobilize from the area.
Glovebox Summary Cost	
Glovebox Inclusive	Single glovebox factor inclusive of all above activities for the gloveboxes in the Sets.
External Piping (TRU-Contaminated)	
Miscellaneous External	Miscellaneous equipment such as heat exchangers.
Piping/Valves	Pipes external to gloveboxes used to transport concentrated plutonium liquids
Vacuum Trap	Knock-out pot in vacuum transfer system used to keep liquids out of the building vacuum system.
Low-Level Contaminated Materials	
Control Panel	Electrical control panel or motor control center for process equipment, pumps, furnaces, etc.
Electric Motor	Motors mounted external to gloveboxes.
Electrical Conduit	Conduit, junction boxes, etc.
External Equip	General equipment not whetted by process liquids or glovebox atmospheres such as chillers
Glovebox Overheat	Glovebox fire detection systems
Tanks	
Remove Raschig Rings	Remove borated glass rings used to fill tanks for criticality prevention
Tank - Annular	In-room removal activities for tanks using an annular configuration for criticality prevention
Tank - Annular-Part SR	Size reduction of parts of annular tanks in a specialized size reduction facility
Tank - Annular-SR	Size reduction of complete annular tanks in a specialized size reduction facility
Tank - Pencil	In-room removal activities for tanks using an pencil configuration for criticality prevention
Tank - Pencil-SR	Size reduction of complete pencil tanks in a specialized size reduction facility
Tank - Raschig Ring	In-room removal activities for tanks using an reaching ring filling for criticality prevention
Tank - Raschig Ring-SR	Size reduction of complete raschig ring tanks in a specialized size reduction facility