A SYSTEMS ENGINEERING APPROACH TO ESTABLISHING A D&D BASELINE

Dr. Michael A. Duffy
Dr. P. Esmailzadeh
Battelle Memorial Institute, Columbus Operations

ABSTRACT

From 1943 through 1986, Battelle Columbus Laboratories (BCL) performed research and development work at its own facilities for the U.S. Department of Energy (DOE) and its predecessor agencies. The most highly contaminated facilities, comprising BCL's Nuclear Sciences Area, are located on 11 acres in West Jefferson, Ohio. Three buildings in this area were used to study nuclear reactor fuels, fuel element components, reactor designs, and radiochemistry analyses: one building contained nuclear hot cells, a second building contained a critical assembly and radiochemistry laboratory, and a third building once housed a nuclear research reactor.

The Columbus Environmental Management Project (CEMP), one of the U.S. Department of Energy - Ohio Field Office's radioactive cleanup sites, is responsible for the decontamination and decommissioning (D&D) of BCL's Nuclear Sciences Area. The CEMP mission is to decontaminate the Nuclear Sciences Area to a condition that is suitable for use without restrictions and to dispose of or store the associated radioactive waste at a suitable DOE-approved facility. To ensure the efficiency and effectiveness of this project, the local DOE office requested preparation of a baseline, suitable for independent validation, establishing the cost and schedule for completing this project.

This paper presents the results of the systems engineering approach used in the preparation of this baseline. An internal group of D&D subject matter experts participated in the application of a functional analysis technique to determine the specific functions for fulfilling the CEMP mission, the requirements that specify how well the functions must be accomplished, and the preferred technical strategies for accomplishing the functions.

Using CORE®, a systems engineering support tool produced by Vitech Corporation, a project model was built that captures the complete set of functions and their relationships, requirements, and strategies. The model was used to track the flow of materials, wastes, samples, and data between functions, ensuring project integration. The D&D subject matter experts also provided cost estimates and durations for individual functions. The functions were then scheduled by level-loading the expenditures over the expected time to complete the entire project. This defined the baseline cost and schedule to completion.

The factors that were determined to be most important in achieving independent validation were (1) the use of a systematic, logical process; (2) the development of a comprehensive model for managing functions, requirements, strategies, issues, and risks; and (3) the identification of realistic project risks and contingencies.

BACKGROUND

On April 16, 1943, Battelle Memorial Institute (BMI) was contracted by the Manhattan Engineering District to perform atomic energy research and development activities. Since that time, BMI has continuously performed research and development work under contract at its facilities for the U.S. Department of Energy (DOE) and its predecessor agencies. The facilities used for these activities are located at BMI's Columbus Laboratories King Avenue Site in Columbus, Ohio, and at its West Jefferson

(WJ) Site in West Jefferson, Ohio. As the result of these activities, fifteen buildings (in part or as a whole) and associated grounds became radioactively contaminated. Six of the buildings are at the WJ Site, which is approximately 15 miles west of Columbus, Ohio. The Battelle Columbus Laboratories Decommissioning Project (BCLDP) for the cleanup of the King Avenue and WJ Sites was established in 1986. The remedial decontamination and decommissioning (D&D) of the King Avenue Site was initiated and is presently near completion. The WJ Site is currently in its early stages of the D&D activities. Three buildings at the WJ South Site with low levels of contamination were decontaminated in 1990. At the present time the D&D activities continue at WJ North, the former Nuclear Science Area, where there is confirmed transuranic (TRU), mixed fission product, and activation product contamination. Figure 1 shows the WJ Site with designation of the contaminated structures and associated areas.

Fig. 1. West Jefferson North Site

Site Description

Three buildings (JN-1, JN-2, and JN-3) and surrounding grounds, which include filter beds and underground drain lines, are the portions of the WJ North Site that are planned for subsequent D&D operation. In JN-1, where retired nuclear cells are located, contaminated materials have been removed, contaminated equipment and the fuel storage pool have been cleaned, and the pool water has been purified and evaporated. This building was used for research in the areas of power reactor fuel performance evaluation, post-irradiation examination of nuclear materials and components, radiation source encapsulation, and physical and mechanical properties of irradiated materials and structures.

Presently, the biological shield and pool in JN-3 are being decontaminated. This building housed a research reactor. Operations began in 1956 and were terminated in 1974. Defueling and partial dismantlement were completed in 1975. Building JN-2, which used to house the critical assembly and radiochemistry laboratories, is now utilized to support the cleanup of JN-1 and JN-3. This building contained a vault for storing special nuclear materials and a radio-analytical laboratory for assay of routine health physics samples and analysis of low-activity and environmental samples.

Waste Inventory

The approach described in this paper yields a baseline of estimated cost and schedule based upon empirical data for the existing waste plus estimates of additional waste that might be generated as a result of the D&D activities. Waste type and waste volume are used as the primary variables from which the scope of activities, activity duration, and preferred D&D strategies and technologies (among other factors) are derived and documented. Table I summarizes the legacy and D&D-generated volumes and waste types for buildings JN-1, JN-2, and JN-3 and underground areas.

Table I. Waste Type and Volume Estimates (Cu. Ft.)

Waste Type	Waste Location			
	JN-1	JN-2	JN-3	Underground
Asbestos	969	9	N/A	1799
Free release	24	3101	N/A	52,768
Hazardous	14,646	522	662	445
Radiological	75,925	18,744	49,632	693,146
Non-Radiological	N/A	N/A	N/A	1,709,138
High-Radiological	390	N/A	N/A	N/A

PURPOSE

As a part of an overall integrated approach to the planning of the D&D activities, development of a cost and schedule baseline was considered critical to future success of the D&D mission at the WJ Site. As mandated by DOE Order 413.3, *Program and Project Management for the Acquisition of Capital Assets* (1), a validated or approved baseline through the "Internal Project Review" (IPR) process is a prerequisite for starting D&D operations or continuing activities that are already under way, as is the case at the WJ Site. The approach applied to the development of the BCLDP baseline was specifically designed to comply with the requirements of DOE Order 413.3 and its two addenda, *Program and Project Management Manual* (2) and *Program and Project Management Practices* (3).

SYSTEMS APPROACH

To ensure a defensible foundation for the BCLDP baseline, identification of all necessary work activities must be based on:

- Implementation of a systematic, logical process
- Identification of all functions (i.e., work) that are both necessary and sufficient to satisfy the BCLDP mission
- Specification of the requirements associated with each function

- Selection of specific technical strategies for performing the functions subject to their requirements
- Assurance of a properly integrated program by maintaining consistency between interrelated functions
- Development of a comprehensive model for managing and controlling functions, requirements, strategies, assumptions, and risks.

A structured process, based on hierarchical decomposition, was used to identify, define, and analyze the functions needed to carry out D&D for each building and area within the WJ North site. The basic approach was to apply the F-R-A (functions-requirements-architecture) process for functional analysis. Functions (F) define what must be done, requirements (R) specify how well it must be done, and architecture (A) identifies the preferred architecture (or strategy) for accomplishing it. This step-wise, hierarchical approach reduces the complexities that the BCLDP would otherwise face when developing an integrated baseline by increasing understanding of what is needed in order to satisfy BCLDP's mission while complying with all applicable laws and regulations. Figure 2 illustrates the sequential nature of the F-R-A process.

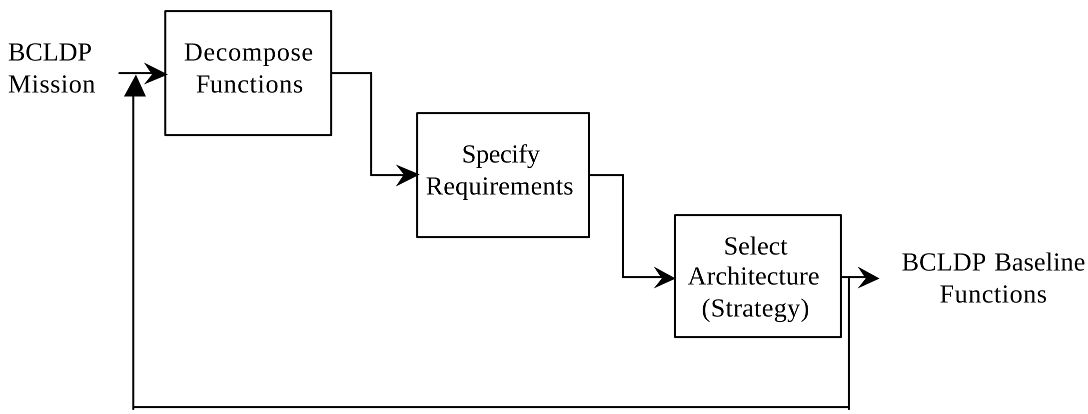

Fig. 2. Functional Analysis Approach

Proper application of the F-R-A process must occur in working sessions composed of a facilitator familiar with the process and a multi-disciplinary team of subject matter experts familiar with all aspects of the D&D work to be done. The experts are responsible for providing the in-depth knowledge needed to decompose the mission into a necessary and sufficient set of functions to satisfy it, to specify all applicable requirements, and to select preferred technical strategies from among feasible alternatives. The facilitator is responsible for guiding the thought process of the experts, mediating the deliberations, and achieving a consensus. This is not necessarily a simple process, since subject matter experts often have difficulty thinking in terms of functions that must be accomplished, as opposed to a collection of physical systems.

RESULTS

The functional analysis was led by a pair of systems engineering facilitators who directed a multi-disciplinary team of BCLDP subject matter experts through the process: experts in waste management, radiological decontamination, radiological characterization, health physics, radiological sample analysis, regulatory concerns, and operational safety. As a first step in the functional analysis, the mission of the BCLDP was explicitly stated:

> *To decontaminate Battelle facilities in a safe, environmentally sound, and cost-effective manner, returning the facilities to a condition suitable for use without radiological restriction.*

The subject matter experts were then asked, "How can the mission be satisfied?" After much deliberation on alternative ways of satisfying the BCLDP mission, the experts reached a consensus on the set of eight 2nd-level functions shown in Figure 3. The experts determined that these eight functions were both necessary and sufficient to satisfy the mission, and hence, represent the minimum amount of work that needs to be accomplished.

Each of the 2nd-level functions in Figure 3 were further decomposed by team members to a level of detail consistent with the needs of a sufficiently comprehensive baseline. As an example of how this process proceeded, the experts were asked, "How can building JN-1 be decontaminated?" Again, there was much deliberation before reaching a consensus on 24 3rd-level functions for JN-1 alone. For simplicity, only three of the 24 3rd-level functions necessary to D&D JN-1 are shown on Figure 3.

Since most of these 3rd-level functions did not yet satisfy the level of detail that would be necessary to prepare detailed cost estimates and schedules, the experts were asked, for example, "How can the high-level cell (within JN-1) be decontaminated?" The experts finally agreed on the four 4th-level functions shown on Figure 3. They were also confident that they would be able to thoroughly describe each of these four functions in terms of what needed to be done (i.e., function description), how well it needed to be done (i.e., associated requirements), and what was the best way to do it (i.e., technical strategy). Thus, the 4th-level functions for decontaminating the JN-1 high-level cell were determined to be sufficient for estimating the necessary resources (manpower, time, supplies, and equipment) to perform the functions satisfactorily.

Requirements applicable to the Columbus Environmental Management Project (CEMP) were extracted from Federal laws, the Code of Federal Regulations, DOE orders, internal procedures, and many other documents. These requirements, which specify how well each of the functions must be accomplished, were assigned to the appropriate functions.

The subject matter experts then generated a number of feasible alternatives for performing each function and systematically discussed their pros and cons. Finally, the team selected a preferred technical strategy that could perform each function and satisfy its complete set of requirements.

At this point data templates were prepared for each of the lowest level functions. These templates contain a definition of the function; a list of the applicable requirements; a description of the strategy selected by the experts for performing the function; a list of all important inputs to, and outputs from, the function; and a list of the necessary assumptions. As an example, Table II shows the data template for Function 1.1.6.3, Decon/Stabilize High Level Cell Surfaces. A total of 323 data templates were prepared: one for each of the lowest-level operational functions (283) in the overall function hierarchy, and one for each of the necessary programmatic support functions (40).

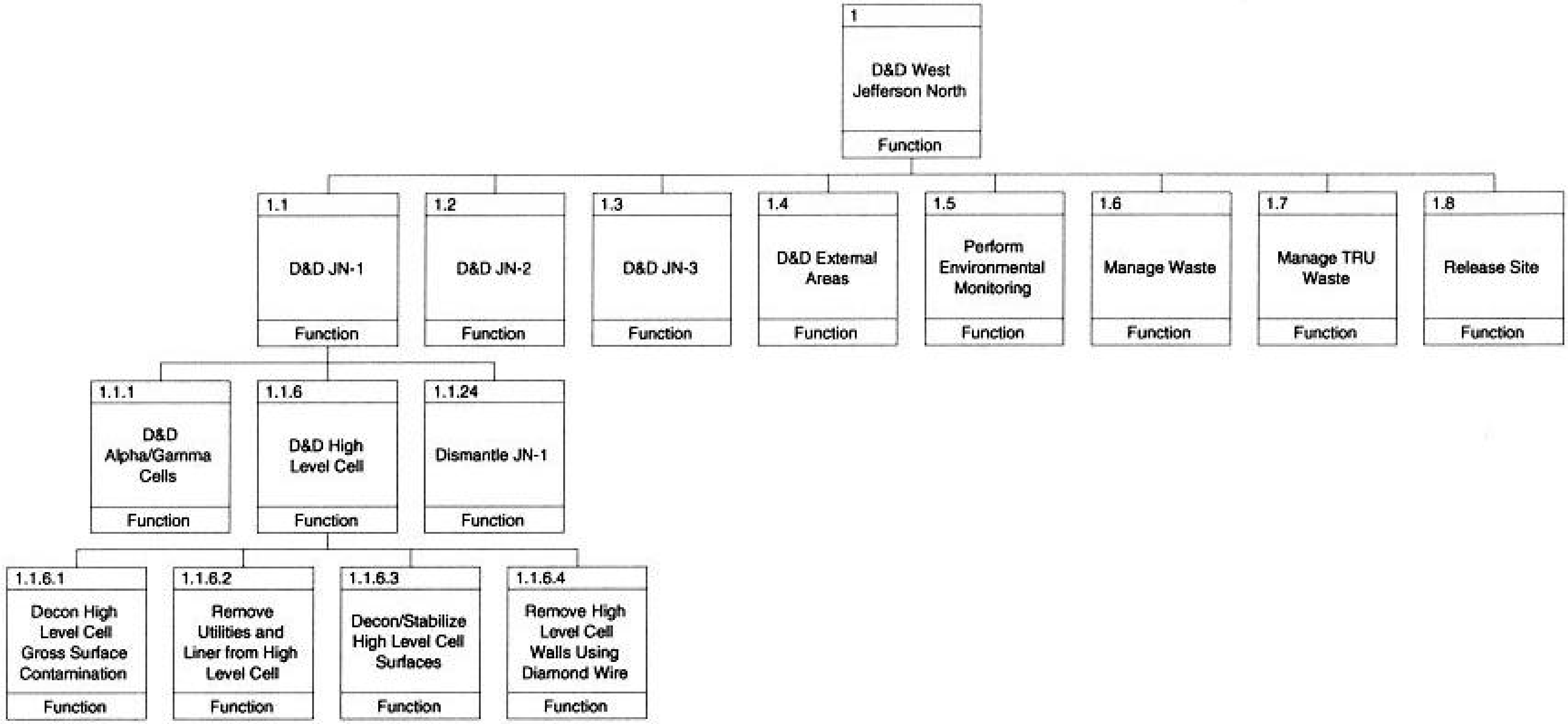

Fig. 3. Partial Hierarchy of Functions for Satisfying the BCLDP Mission

Table II. Data Template

☒ **JN-1** ☐ **JN-2** ☐ **JN-3** ☐ **Ext. Area** ☐ **Env. Mtr** ☐ **TRU/Waste** ☐ **Release Site**

Function No: 1.1.6.3 **Activity No.:** C004 **Work Pkg. No.:** 7C41-B03

Function Name: Decon/Stabilize High Level Cell Surfaces

Component Name: HLC

Function Description: Paint out and seal the surfaces of the HLC structure so there is no smearable contamination and minimal exposure for the HLC structural removal.

Basis of Estimate

Strategy for Accomplishing Function: Generate a work instruction package to perform the decontamination and stabilization of the HLC structure. Paint and strip, if necessary, the HLC structure to lower smearable contamination and overall inventory. Seal the HLC structure in preparation for structure removal.

Applicable Requirements/Procedures:

DD-90-02; DD-93-04; DD-OP-075, 076; HS-AP-4.0, 5.0; HS-OP-001; HP-AP-1.0, 2.0, 5.0, 8.0; HP-OP-012; PR-AP-17.1; QD-AP-5.2, 6.1; RL-AP-1.0; SM-OP-001; TD-AP-2.0; WA-OP-020

Input Descriptions:

1. HLC ready for decontamination

Output Descriptions:

1. Approximately 20 cubic feet of secondary (PPE) waste
2. Approximately 20 cubic feet of stripped ALARA paint
3. The HLC structure is ready to be removed

Assumptions:

1. The HLC is essentially non-smearable and does not pose undue exposure risk to personnel.
2. Manpower, equipment, resources, and the area are available for this activity when scheduled
3. There are no RCRA constituents in the structure.
4. Production rates include 5 days to paint and strip, and 5 days to seal prior to cell structure removal
5. The work instruction and procedures are in place sufficiently early to perform this activity on schedule.

Estimated Time to Plan the Work (Including Review and Approval): this work is integrated into 1.1.6.2

Estimated Resources Required to Plan the Work

In the following table, for each appropriate labor type enter the # of Persons involved in planning the activity, the # of Days (full or partial) they will be involved, and the total # of person-Hours necessary to plan the work, e.g., 2/5/36

Table II. Data Template (continued)

Labor Type	Code	Persons/Days/Hours
Manager/Senior Staff	HBB	
Technical Advisors	HBTA	
Project Manager/HP Manager	HBPM	
Task Leader	HBTL	
Secretary/Clerical	HBS	
Support Professional	HBP	
Bartlett Health Physics	HRH	

Estimated Time to Perform the Work: 10 Days

Estimated Resources Required to Perform the Work

In the following table, for each appropriate labor type enter the # of Persons working on the activity, the # of Days (full or partial) they are involved, and the total # of Hours necessary to perform the work; the PPE/Laundry Group to be used during the performance of the work; and the Total # of Jumps; e.g., 4/20/640 Group 1 160

Labor Type	Code	Persons/Days/Hours	PPE/Laundry Group	Jumps
Program Manager	HBA			
Manager/Senior Staff	HBB			
Technical Advisors	HBTA	1 / 10 / 10		
Project Manager/HP Manager	HBPM	2 / 10 / 20		
Task Leader	HBTL	1 / 10 / 80	Group 0	10
Battelle Technician	HBT			
Battelle Technician O/T	HBTO			
RAL Staff	HBL			
Support Professional	HBP	1 / 10 / 8		
Secretary/Clerical	HBS			
Decon Ops Hourly	HBH			
BCO Support	HBCO			
BCO Skilled Laborer	HCE			
BCO Skilled Laborer O/T	HCEO			
BCO Facility Manager	HCF			
Bartlett Technician	HRD	2/ 10 / 160	Group 1	30
Bartlett Maint Specialist	HRDS	1 / 10 / 40	Group 0	10
Bartlett Health Physics	HRH	1 / 10 / 80	Group 1	15
Bartlett Admin Support	HRA			

Subcontract/Purchased Service: None

Special Equipment/Material: ALARA paint – 95 gallons = $9,644;
Epoxy Paint – 200 gallons = $11,730

Comments/Explanations: None

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A primary objective of this effort was to ensure a well-integrated program. N-squared diagrams proved to be useful in leading the participants to thoroughly understand and precisely communicate all the interrelationships between functions. By explicitly showing the primary inputs and outputs between functions, these diagrams also facilitated systems integration and a common view of the D&D program. Figure 4 is a representative example of an N-squared diagram for Function 1.1.6, D&D High Level Cell.

Once the subject matter experts provided manpower estimates and durations for individual functions, the functions were scheduled by level-loading the estimated expenditures over the expected time to complete the entire project. This defined the draft baseline cost and schedule to completion.

Using CORE® (4), a systems engineering support tool produced by Vitech Corporation, a project model was built that captures the complete set of BCLDP functions, requirements, strategies, inputs, and outputs. In addition to organizing the function hierarchies and N-squared diagrams, the model is used to track the flow of materials, wastes, samples, and data between functions, thereby ensuring project integration.

NEXT STEPS

The draft baseline is part of an integrated planning process currently underway for the long-term management of the BCLDP. The planning system and its implementation are driven by the requirements of DOE Order 413.3, a major component of which is the development of a risk management plan and process. The draft baseline included a preliminary probabilistic risk analysis based on a consideration of three sources of risk:

- Uncertainties associated with the waste volume estimates and several other factors related to waste management (e.g., on-time availability of a waste disposal facility)
- Uncertainties in the assumptions regarding specific future events and decisions
- Uncertainties in the effectiveness of technical strategies selected for specific functions.

During the Independent Project Review by DOE/EM-6, the need to expand the risk analysis and its application in estimating cost and schedule contingencies was determined to be important to ultimately achieving an approved baseline. The preliminary risk analysis results will be used to prepare a comprehensive Risk Management Plan, in accordance with DOE Order 413.3. A more extensive risk management effort will be undertaken to ensure that a risk-based decision-making approach is used to continually update the cost and schedule baseline over the life cycle of the BCLDP.

CONCLUSIONS

A logical, consistent process, relying on experienced technical staff and managers to provide expert knowledge, was used to establish a firm foundation for the BCLDP project's draft baseline. The process identified 323 specific work activities that are necessary to successfully satisfy the BCLDP mission. A comprehensive process model, incorporating all operational activities, was developed to support future analyses and ensure project integration. DOE/EM-6's Independent Project Review team assigned a grade of 96% to the technical scope portion of the draft BCLDP baseline. The review team acknowledged that the use of a systems engineering approach resulted in a very well integrated baseline. They also concluded that the data templates were an effective means for documenting the results and are considering whether other projects throughout the DOE complex might benefit from adopting these data templates.

HLC minus removable material (968 sq ft contaminated surface area)				
1.1.6. 1 Decon High Level Cell Gross Surface Contamination	HLC minus gross decontamination			1 alpha isotopic sample 10 alpha/beta samples LLW (90 cu ft) Mixed waste (12 cu ft) TRU (10 cu ft)
	1.1.6.2 Remove Utilities and Liner from High Level Cell	HLC ready for decon		12 gamma spec samples ALARA paint (20 cu ft) LLW (150 cu ft) Rad lead waste (150 cu ft) Second. waste (200 cu ft)
		1.1.6.3 Decon/Stabilize High Level Cell Surfaces	HLC structure ready to be removed	ALARA paint (20 cu ft) Second. waste (20 cu ft)
			1.1.6.4 Remove High Level Cell Walls Using Diamond Wire	Consumables (500 cu ft) Cut concrete (6000 cu ft) Water/sludge (100 cu ft) Job control (250 cu ft)

Fig. 4. N-Squared Diagram for D&D High Level Cell

REFERENCES

1. DOE Order 413.3, Program and Project Management for the Acquisition of Capital Assets, October 13, 2000, Draft
2. DOE Order 413.3, Program and Project Management Manual, October 2000, Draft
3. DOE Order 413.3, Program and Project Management Practices, October 2000, Draft
4. CORE®, Automated Support for Systems Engineering, Vitech Corporation, www.vtcorp.com