Advanced Fuel Cycle Cost Basis Report: Supporting Documents 2 Production Based Costing

Nuclear Fuel Cycle and Supply Chain

Prepared for

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Systems Analysis and Integration

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This is just a reformatting of previous work to the current format for rerelease of the entire report so there is no primary technical developer or lead author. J. Hansen (INL) and E. Hoffman (ANL) can be contacted with any questions regarding this document.

PRODUCTION BASED COSTING

A1-1.1. Introduction

The purpose of this section is to outline a method of cost analysis whereby a significantly better representation of "should achieve" costs may be attained for NOAK systems. Based on economists' notions of producer theory, and grounded in the cost analysts' and project managers' tool called the Work Breakdown Structure (WBS), this section describes best practices in cost estimation. It then illustrates how the Code of Accounts (COA) structure, developed by the Economic Modeling Working Group (EMWG) of the Generation IV International Forum in "Cost Estimating Guidelines for Generation IV Nuclear Energy Systems [EMWG 2007] (hereafter "Gen IV Guidelines Document"), can be used to differentiate "should achieve" versus "did experience" costs.

Economists use the theory of production, among other purposes, to analyze how technology specifies the combination and transition of inputs to process or system output. Think of output as a product, process, project, or service – anything that results from combining and/or processing inputs. The inputs into production are commonly grouped as land, labor, and capital where capital in this case refers to physical (as opposed to financial) resources such as machinery or equipment. Governed by the science and engineering of the technology being represented, the production function models how inputs combine to form output. Graphically technology is represented as the shape of the production function: P=f (input1, input2)

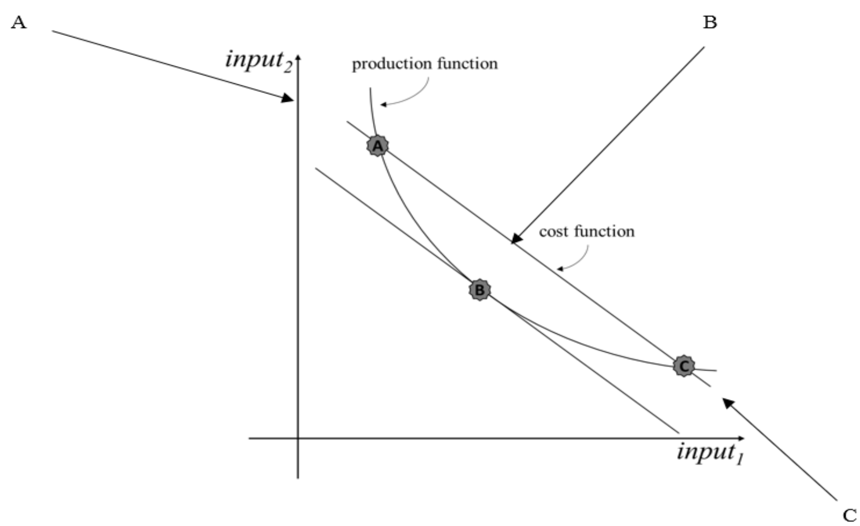

Figure 1. Stylized Representation of Producer Theory.

Figure 1 shows a simple, stylized model of a production function. In it, two inputs combine according to some level of technology result in product output. Three points (could be labeled as A, B, C top to bottom) show possible input combinations that will produce a fixed level of output, $P_{constant}$. In fact, any combination of inputs along the production function illustrates alternative ways of using inputs to produce the same level of output. Not illustrated, increasing levels of production correspond to the production function moving to the upper right of the figure. So, input combination 'A' results in the same level of output as 'C' although 'A' favors input 2 while 'C' favors input 1. As an example, one can think of this simplistic model representing a surveillance facility. Surveillance is the output and inputs 1 and 2 might be people and cameras, respectively. The level of people and cameras can be adjusted in many combinations, each combination producing the same level of surveillance.

The production function can be thought of as a three dimensional "response surface" (Fig 2) which is a function of input1 and input2 (the figure below is a generic example). On a map, altitude would be a function of x and y coordinates, and a "contour" [line of constant altitude] would be a curve similar to our production function above where P (input 1, input2) = $P_{constant}$.

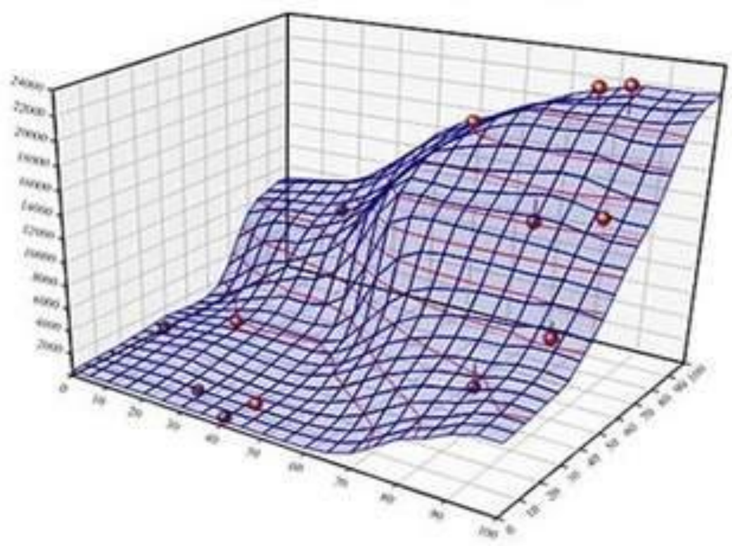

Figure 2. Production Function as Three Dimensional Response Surface

Composed of input prices and budgetary expenditure, Figure 1 also illustrates two cost functions that are separated by expenditure level. Like the production function, increasing costs are represented with cost functions increasing to the upper right of the figure. The intersection of the cost function with the production function represents the expenditure necessary to pay for the corresponding input combination. Points 'A' and 'C' are on the same cost function, indicating that to produce output with either level of input combination results in the same level of expenditure. But point 'B' is on a different cost function. It indicates that the same level of output (technical performance) can be attained with the input combination given by 'B'. That is, 'B' indicates the combination choice that attains the least cost of producing the stylized level of output, i.e. performance. Essentially the performance is "cost optimized" with respect to the two variable inputs.

Input combination 'B' indicates what producing the represented level of output should cost. Points 'A' and 'C' can both produce the same level of output, but 'B' is clearly a better way to combine resources and minimize cost. The WBS is the analytic tool that cost analysts use to organize input requirements for some type of output – be it a process, product, service, or project – so that cost can be assigned to all necessary inputs. For analysis of nuclear projects, the code-of-accounts (COA) is the tool for keeping track of input costs in a systematic manner. Together these facilitate identifying the least cost alternative, such as point 'B' in the simple model.

A1-1.2. Organizing Structures

Organizing the elements of a system into some type of structure is critical for accurately estimating cost. The organizing structure should be one that specifies all that is required in order to produce output [Stewart 1991]. Such a structure provides a clear assessment of what is included in the project, product, or service. A well-defined organizing structure articulates partitioned information, becoming a communication tool about the project to various implementation perspectives, such as system engineering and program management [GAO, 2009]. The organizing structure is needed to accurately estimate cost, schedule, and budget; however it, is also valuable in identifying where risks may exist in the project or where crucial information may be missing. Analogous to the simple model in Figure 3 the organizing structure should represent at least two perspectives: the set of inputs required to produce output, and the cost of those inputs. A WBS and the corresponding COA are two analytic tools that can be used in conjunction to reflect the two important perspectives (inputs and costs) in an organizing structure.

A1-1.2.1. Work Breakdown Structure (WBS)

A seminal text on in the field of cost analysis indicates that the first step in cost estimating is to produce a WBS for the system to be analyzed [Stewart 1991]. Similarly, guidance on cost analysis for US government projects indicates that the "WBS is the cornerstone of every program because it defines in detail the work necessary to accomplish a program's objective" [GAO 2009, p. 65]. The WBS arranges inputs into a hierarchy where inputs accumulate to the output under analysis. Figure 3 is a simple representation of a WBS from the US Government Accountability Office GAO).

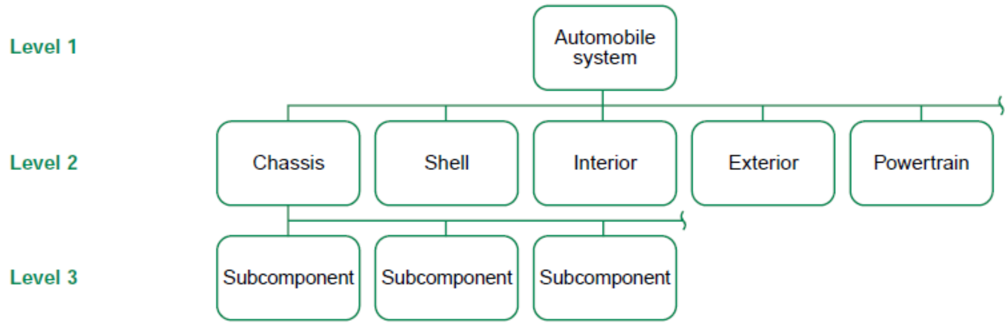

Figure 3. Product-Oriented Work Breakdown Structure (GAO, 2009, p. 66).

Figure 3 shows a simple example of a WBS for an automobile system. In it the automobile system (indicated as Level 1 of the hierarchy) is the output under analysis. Level 2 divides the output into components necessary in order for the system to work. Level 3 disaggregates each component into subcomponents. Level 3 may or may not be the level where inputs are assigned. The hierarchy continues until components can no longer be disaggregated so the levels of the hierarchy adjust with the level of specificity and complexity of the components in the activity. As Stewart describes, the WBS is the framework for collecting, accumulating, and organizing work activity by the outputs under consideration [Stewart 1991]. Its essential function is to divide output into the major activities and elements (or components) necessary to accomplish the work [Stewart 1991]; [GAO, 2009].

A WBS communicates information. It informs those using it of the inputs that have been accounted for in the structure. This reduces duplicity because inputs in the WBS must follow the principle of being mutually exclusive and being collectively exhaustive, i.e. without serious data omissions. If inputs can be used in more than a single element of the WBS, then input allocation can be handled in at least two ways. The input can be assigned to the element where it will have the majority of use, or it can be split up into more than one element where it will be used. (This is discussed in more detail later in the cross-walking discussion). Finally, the WBS is accompanied by a "WBS dictionary" that defines what the analyst has included in each element of the structure. For example, an accompanying dictionary would answer questions about what the analyst meant by "Chassis" when it was listed in the WBS in Figure 3.

A1-1.2.2. Code of Accounts (COA)

Originally set up as the Energy Economic Data Base (EEDB) by the Atomic Energy Commission-Energy Research and Development Administration, then later adjusted to fit the purposes of the International Atomic Energy Agency (IAEA), the Economics Modeling Working Group (EMWG) of the Generation IV International Forum most recently developed the Code of Accounts (COA) [EMWG, 2007]. Itself an organizing structure, the COA details how to account for various components of nuclear systems [EMWG 2007]. In the spirit of this section, the COA is a hierarchical organizing structure. The discussion on COA herein will sound very similar to the WBS above. They are, in fact, very similar. But like the simple model in Figure 3 illustrates, each represent different perspectives of the same system.

The COA organizes costs; it is an accounting structure that can be applied to various types of nuclear, and even non-nuclear, systems. Similar to the WBS, the COA is organized in a hierarchical fashion and for this application enumerated with a 2-digit level coding system. The original EEDB COA structured a 5-digit system, essentially drilling down to the level of small pumps and transformers, but that level of detail for a nuclear power plant would result in over 100 plus pages of densely-written text. As the COA can be used to estimate total lifecycle cost of a system, six categories of the COA are to account for costs in building a facility while three account for the use and disposal of the system. Table 1 shows the COA structure used to compute investment cost and Table 2 shows the COA structure for estimating operations and maintenance. Accompanying the COA, and again similar to the WBS, is a dictionary of what belongs in each account. This dictionary is located in Appendix F of the Gen IV Guidelines Document.

Table 1. Generation IV International Forum Nuclear Energy Plant Code of Accounts [EMWG 2007, p. 30].

Account Number	Account Title
1	Capitalized Pre-Construction Costs
11	Land and Land Rights
12	Site Permits
13	Plant Licensing
14	Plant Permits
15	Plant Studies
16	Plant Reports
17	Other Pre-Construction Costs
19	Contingency on Pre-Construction Costs
2	Capitalized Direct Costs
21	Structures and Improvements
22	Reactor Equipment
23	Turbine Generator Equipment
24	Electrical Equipment
25	Heat Rejection System
26	Miscellaneous Equipment
27	Special Materials
28	Simulator
29	Contingency on Direct Costs
Direct Cost	
3	Capitalized Indirect Services Costs
31	Field Indirect Costs
32	Construction Supervision
33	Commissioning and Start-Up Costs
34	Demonstration Test Run
Total Field Cost	
35	Design Services Offsite
36	PM/CM Services Offsite
37	Design Services Onsite
38	PM/CM Services Onsite
39	Contingency on Indirect Services
Base Construction Cost	
Account Number	**Account Title**
4	Capitalized Owner's Costs
41	Staff Recruitment and Training
42	Staff Housing
43	Staff Salary-Related Costs
44	Other Owner's Capitalized Costs
49	Contingency on Owner's Costs
5	Capitalized Supplementary Costs
51	Shipping and Transportation Costs
52	Spare Parts
53	Taxes
54	Insurance
55	Initial Fuel Core Load
58	Decommissioning Costs
59	Contingency on Supplementary Costs
Overnight Construction Cost	
6	Capitalized Financial Costs
61	Escalation
62	Fees
63	Interest During Construction
69	Contingency on Financial Costs
Total Capital Investment Cost	

Table 2. Structure of the Generation IV International Forum Operations and Maintenance Code of Accounts [EMWG 2007, p. 33].

Account Number	Account Title
7	Annualized O&M Costs
71	O&M Staff
72	Management Staff
73	Salary-Related Costs
74	Operations Chemicals and Lubricants
75	Spare Parts
76	Utilities, Supplies, and Consumables
77	Capital Plant Upgrades
78	Taxes and Insurance
79	Contingency on Annualized O&M Costs
8	Annualized Fuel Cost
81	Refueling Operations
84	Nuclear Fuel
86	Fuel reprocessing Charges
87	Special Nuclear Materials
89	Contingency on Annualized Fuel Costs
9	Annualized Financial Costs
91	Escalation
92	Fees
93	Cost of Money
99	Contingency on Annualized Financial Costs

The two-digit coding shown in the tables above can be disaggregated to reveal a greater level of specificity, and for earlier nuclear power cost-experience studies sponsored by DOE-NE and its predecessors in the 1975-1988 timeframe NPPs were broken down to the five digit level under the EEDB program. The guidelines document [EMWG 2007] articulates how the accounts coding should be adjusted based on facility type and purpose. For example a numerical code in the structure indicates if the system under analysis applies to units, plants, systems or facilities, or commodities. Further, facility type designates a code depending on the facility function, i.e. power plant, fuel fabrication, fuel reprocessing, desalination, hydrogen generation, other processes, or waste repository [EMWG 2007, Appendix F].

The COA in the Gen IV Guidelines Document evolved from a previous structure developed by the IAEA. IAEA developed a structure, basically based on the US EEDB mentioned above, to aid developing countries in analyzing the quality of bids for nuclear power plant projects. The IAEA built the structure with the thought that it would be completed as a useful tool with the help of vendors, architect-engineers, and constructors from industrialized countries. The EMWG re-organized how the structure was originally developed because the IAEA bid evaluation type structure led to inherently high-level estimates. EMWG re-tooled it to allow for greater specificity, primarily changing the labor accounting.

A1-1.2.3. Cross-walking WBS and COA

The WBS and the COA provide two perspectives of the same information, but together can fit into an organizing structure to enable a better understanding on “should” costs and “did” costs. The WBS is an organizing structure that supports identifying all inputs (materials, labor, equipment, etc.) needed to produce output (a functional facility). The COA is an accounting structure that applied to WBS provides information on input cost. For example, COA 21 is for civil structures and improvements. In a WBS applied to a nuclear system, COA 21 would likely be applied over several WBS elements. The COA structure, detailed in the Gen IV Guidelines Document, has a coding system whereby specificity greater than two digits i.e. the ability to drill deeper into an estimate beyond the basic subsystem (civil, nuclear island, electrical, heat removal et al) level can be attained. Using the COA in tandem with a detailed WBS for nuclear systems will support the analyst’s ability to identify the “should cost” (target achievable cost) of a system.

A1-1.3. References

EMWG 2007 – *Cost Estimating Guidelines for Generation IV Nuclear Energy Systems.* Gen IV International Forum: OECD Nuclear Energy Agency, 2007.

GAO 2009 – *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*. United States Government Accountability Office, 2009.

Stewart 1991 – Stewart, R.D., *Cost Estimating, 2nd Edition*, John Wiley & Sons, 1991.