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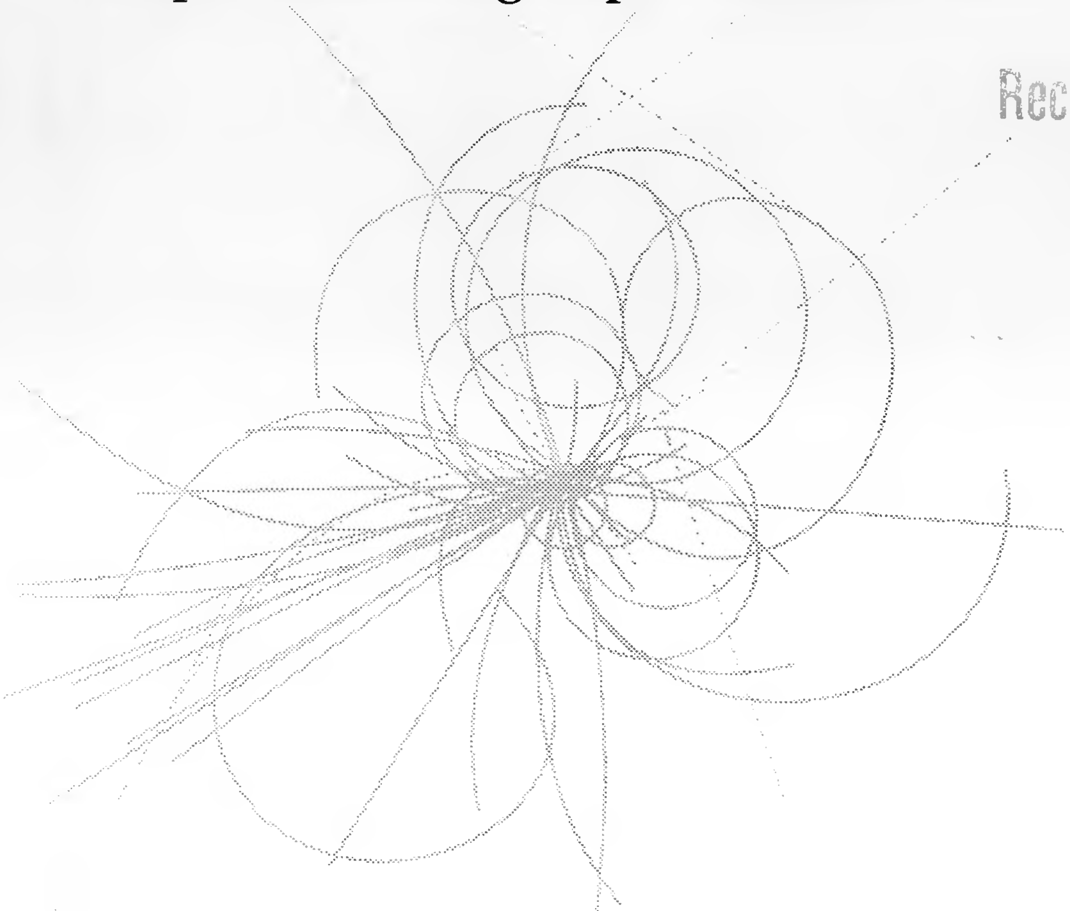
Superconducting Super Collider Laboratory



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SYSTEMS ENGINEERING AT THE SUPERCONDUCTING SUPER COLLIDER (ONE YEAR LATER)

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Abstract: After one year of systems engineering at the Superconducting Super Collider (SSC), the project baseline of costs, schedule milestones, and top-level (point design) physics parameters has been accepted by the Department of Energy (DOE). This paper describes the role of systems engineering in developing the baseline and in establishing requirements specifications, change control, and methods of tracking to a baseline. The differences between the Department of Defense and DOE—specifically at the SSC Laboratory (SSCL)—in application of systems engineering disciplines and tools are discussed. The aim of the paper is to inform participating industries of the anticipated requirements format and of the emphasis that will be placed on physics requirements as opposed to procedures. Industry subcontractors should have a better understanding of the systems engineering expected by the SSCL.

INTRODUCTION

The paper begins with a definition of systems engineering, develops the theme of baselines through the systems engineering tools used, and closes with conclusions and a statement of what subcontractors can expect when bidding to support the SSC.

SYSTEMS ENGINEERING

Systems engineering was defined at the 1990 IISSC as "the management function which controls the total system development effort for the purpose of achieving an optimum balance of all system elements. It is a process which transforms an operational need into a description of system parameters and integrates those parameters to optimize the overall system effectiveness." This definition is adequate in a classical systems engineering environment such as an aerospace company, but it is impractical in the environment of the Superconducting Super

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Collider Laboratory (SSCL). Two phrases make it impractical: "controls the total systems development effort" and "a process which transforms an operational need into...." First, let there be no doubt that systems engineering does not control the system development effort. The scientists, specifically the physicists, control the technical management and the technical systems, and thus control the technical systems, and thus control the development. Second, the physicists describe the system parameters and integrate those parameters.Systems engineering is a tool to help bring some discipline to the process, to document and track the process, and to support development of "procedures" (as understood at the SSCL), including the process of availability (reliability and maintainability), logistics, safety, materials, etc. This author offers a different definition of systems engineering, one proposed at a Lockheed Corporation systems engineering task force meeting: "Whatever it takes to get what you want." This simple definition says it all. But note that it does not say, "Whatever it takes to get the job done." It is possible, even probable, that one can get the job done without getting what he wanted. With this definition as a guide, we can proceed to develop baselines (including specifications and interfaces), configuration management, and specialty engineering procedures.

BASELINES AND SYSTEMS ENGINEERING TOOLS

The Department of Defense (DOD) uses three kinds of technical baselines: functional, allocated, and product. The functional baseline is a high-level baseline usually formed by the system specification. The allocated baseline is formed by the development specifications flowing out of the system specification. This includes the "design to" requirements for the subsystems and components. The product baseline is set by "build to" specifications for subsystems or components which consist of a complete set of drawings and specifications which have been validated through testing of prototypes. This product baseline allows mass production of subsystems and components. At the Department of Energy (DOE), Order 4700.1, Chapter III, defines functional, technical requirements, design requirements, and final baselines. One way to think of these requirements, though imprecise, is the association with 30, 60, and 90 percent complete. DOE alludes to Title I design, which is associated more appropriately with construction than with technical systems. In contrast, DOD technical baselines apply more to technical systems than to construction. The SSC deals heavily with both technical systems and construction, and demands a total integration of the two. This sometimes confuses the definition and application of traditional baselines.

The definitions of technical baselines are not as important as the fact that there is a baseline, that baseline is established by *approved* specifications, and those specifications allow one to "design to" or "build to". At the SSCL, the functional baseline is the Site Specific Conceptual Design Report (SCDR), SSCL-SR-1056, July 1990. The lower level baselines are developed to create the detail which supports the functional baseline. The baseline is not formed at one time; it is formed as the detailed specifications are approved.

Once established, the baseline is controlled through configuration or change management; i.e., no changes are made to the baseline unless they are justified, approved, and documented. Anyone can originate a change and prepare a change package. The change package includes the requested change (as compared to the baseline), reason for the change, and the technical, cost, and schedule impact of making or not making the change. The Configuration Management Plan depicts the levels of change authority for the project, from the DOE through the SSCL divisions. Changes may be approved by the chairman of the change control board at the appropriate level of authority. Change packages are discussed with the members of the board but there is no vote. The change control board is chaired by the Project Manager, who has sole authority to approve or disapprove changes at the project level. Configuration management then tracks the changes to ensure that they are implemented and that a trail of the machine configuration is documented and maintained.

Systems engineering is a tool for project management to establish and maintain baselines. At the SSCL, systems engineering personnel reside within the divisions to assist in establishing and tracking lower level baselines. This discussion continues with emphasis on the technical baseline and assumes that the reader understands that cost and schedule baselines are also established and tracked. The tools for systems engineering to use are discussed in the following paragraphs.

Plans

Several plans, e.g., Project Management, Systems Engineering Management, Configuration Management, Reliability, and Software Development, are key to the structure for establishing and controlling the technical baselines. Note that major subcontractors will be expected to establish and control baselines on their product(s) and to produce similar plans as stand-alone or as supplements to be compatible with the SSCL plans. Subcontractors will receive copies of the SSCL plans if they are requested to provide such plans for the items to be produced. The Project Management Plan, completed January 28, 1991, SSCL control number P40-000021, is an agreement between the SSCL and the DOE on how to conduct business. Section 7, Configuration Management, and Section 11, Systems Engineering, set the stage for conduct of systems engineering at the SSCL. For brevity, the various other plans will not be discussed in this paper.

Specifications

DOD specifications usually follow the format of Mil-Std-490A, a time-tested, recognized method of formatting specifications. However, at the SSCL, the Mil-Std-490A format is believed to be too cumbersome, at least at the highest levels of specifications. These include the system and segments at the machine level: Collider, Linear Accelerator, Low Energy Booster, Medium Energy Booster, and High Energy Booster (levels 1, 2, and 3A in Figure 1). This philosophy entails depiction of physics parameters in tables such that they are readily accessible, without unnecessary verbiage, to physicists and engineers at the SSCL. This format will be also be used at the next level, 3B (elements for each of the above referenced machines). All of these levels of specifications will stay within the SSCL and do not, per se, result in procurements. Thus the process of brief, tabular specifications will be used for all specifications that are perceived as for use only to inform those at the SSCL of the physics requirements. The top level procedures—reliability, safety, logistics, etc.—will be documented separately in SSCL standards or procedures. These procedures will be prepared by the engineering standards group, in conjunction with the engineering groups, and will be published for the entire SSCL. These procedures will also be available for subcontractors, if required.

The engineering requirements normally found in specifications are discussed in the lower level specifications, level 4 and below, on the specification tree (Figure 1). These lower level specifications will be used to procure items; consequently, they require more detail for engineering requirements and will be in a format that industry is accustomed to seeing. That does not mean that the format will always be Mil-Std-490A. We have already seen a combination of formats at level 4. The collider dipole magnet specification is in Mil-Std-490A format, and the subcontractors have also been requested to prepare the flow down specifications in Mil-Std-490A format. The specification for the refrigerator plant was in another format which set out the requirements but assumed a continuing dialogue between the contractor and the SSCL to complete the requirements and the subsequent design. This particular specification was criticized for lack of "procedures," specifically reliability and safety considerations. However, subcontractors may see this type of specification again, particularly a small or disadvantaged subcontractor or one who is known not to have participated in large government contracts. This does not diminish the need for the subcontractor to provide a quality product, but it does relieve the burden that is sometimes perceived with a Military Standard. The point is that specifications will be in any format acceptable to both the SSCL and the subcontractor as long as the result is what the SSCL needs. Content and ability to determine the requirements to produce a quality product are the drivers; format is not.

Interface Control Working Groups

The interface definitions will be developed by the Interface Control Working Group (ICWG) under Dr. Don Edwards, head of the Accelerator Design and Operations Division. It is proposed that the ICWG oversee development of interface requirements, assign the individuals to do the work, direct the development, monitor the progress, and approve the interface document. The ICWG would be made up of the division heads or deputies, or at a minimum, the technical group leaders. Each required interface document would be assigned to an interface control working panel (ICWP) made up of members assigned by the ICWG. That is why such high-level membership is required on the ICWG. In the absence of an approved process, the ICWP is operating under this influence but with individual charters. At the present time there are two interface control working groups: one between the cold magnets and the spool (corrector magnets), and one required for the Accelerator System String Test (ASST). Systems engineering is an integral part of both of these interface groups. Systems engineering personnel bring the engineering parties together to work out the interfaces, follow up on the action items, and document the interface requirements.

Configuration Management

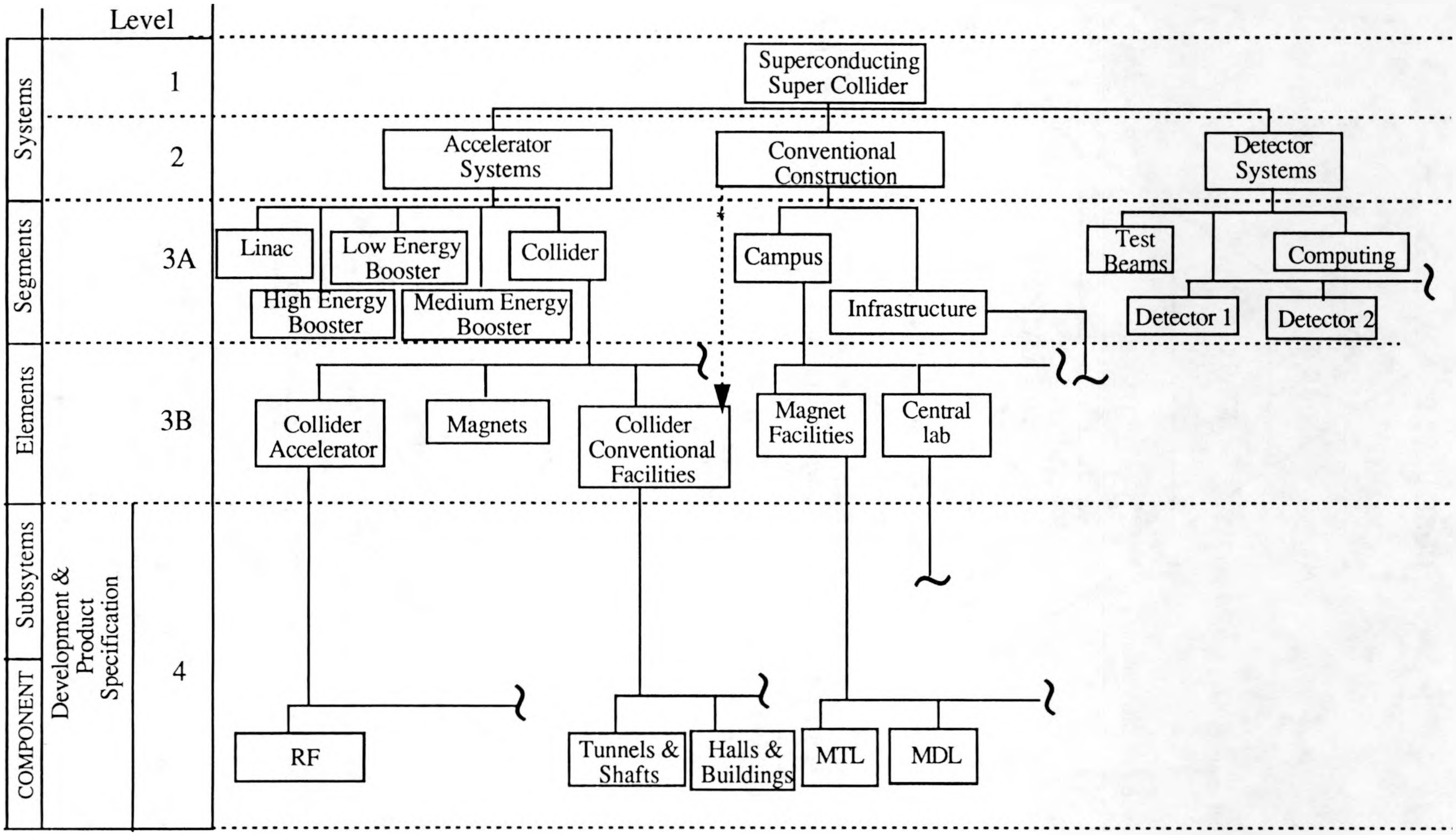
Configuration Management is more than just change control as depicted in Figure 2. It actually deals with knowing what the SSCL has and with ensuring that everyone is working on the correct set of documentation. The baseline and configuration management meticulously protects the baseline. When changes are approved, configuration management ensures that the change is properly distributed through document control. Document control is responsible for releasing a document or a change. The document is available in a central library and anyone can obtain a current version. This guards against the possibility of someone obtaining a copy of an out-of-date version from another person. Configuration management keeps careful records so that the status of approved changes is known, whether they are pending or implemented, and how many units (if applicable) are affected.

Subcontractor/vendors are required to manage their configurations in a similar fashion so that the product delivered to the SSCL is well-documented and its makeup can be verified. As a final item, configuration management participates in reviews and audits. Reviews may result in a change to the baseline; audits verify that the product meets specifications.

Design Reviews

DOE Order 4700.1 lists the reviews that the SSCL must conduct to manage the project from the DOE perspective. These reviews are also required by the Project Management Plan. Figure 3 depicts the reviews on a time line relative to the design phase, along with the types of specifications that accompany the reviews. These reviews include the Systems Requirements Review, Preliminary Design Requirements Review, Preliminary Design Review, and Critical Design Review, sometimes called the Final Design Review.

The Systems Requirements Review, not shown on the chart, is complete. The results are contained in the SCDR and in the minutes of the June 1990 review.



* Construction guidance will be used from the level 2 specification but technical guidance will be from the technical system supported.

Figure 1. Example of Specification Tree.

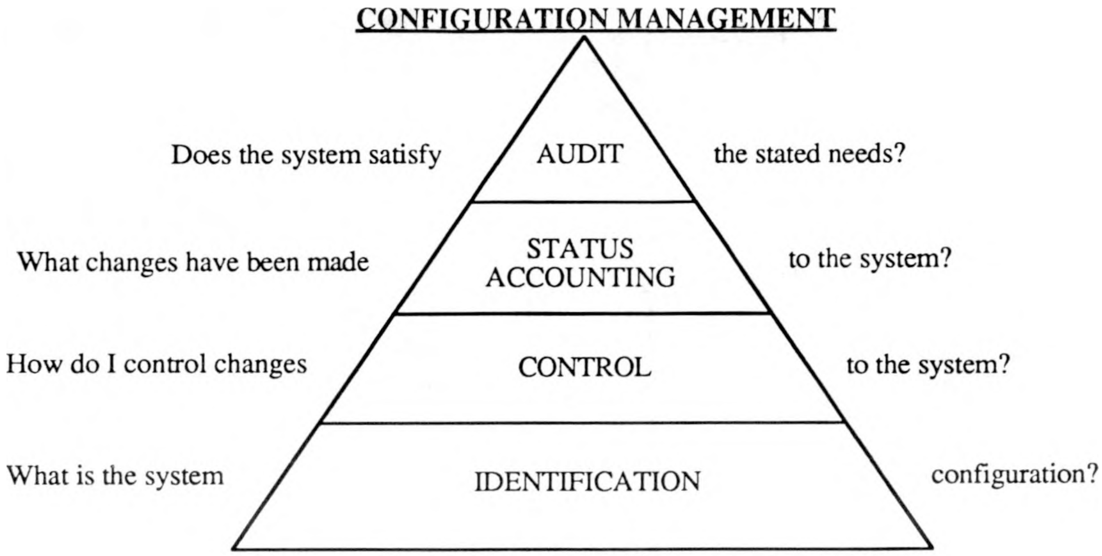


Figure 2. Configuration Management.

The Preliminary Design Requirements Review (PDRR) establishes the basis for developing the specifications and launches the preliminary design. The PDRR also approves expenditure of funds for long lead items for prototype development. Often, design is begun in the absence of knowledge or documentation of the requirements. The result may be costly if the design needs to be done again because the requirements were not well understood or because there was a difference in interpretation between the user and the designer.

The Preliminary Design Review (PDR) sets the stage for the "design" to phase of the project. It initiates detailed design and allows expenditure of funds for long lead item procurement. The types of information available in the PDR correspond to the types of information required for a Title I review for construction. Development specifications available in the PDR correspond to the Work Authorization Documents prepared for the construction contractor.

The Critical Design Review (CDR) precedes the "build to" phase of the project. It allows expenditure of funds to begin production. The types of information available for the CDR correspond to the types of information at a Title II review for construction, albeit, 60 percent or 90 percent complete.

Other reviews may be held to convey specific information. Two such reviews are Test Plan Reviews and Production Readiness Reviews. These will be held on an as-required basis. As required, for subcontractors, means as stated in the contract.

Technical Performance Measurements

Technical performance measurements are progress or status reports/analyses on items of high interest or high risk. Currently, the Project Manager has a list of 12 items, including each of the injector machines, which are reviewed once each month. The reviewers, task leaders for the project, spend about 30 minutes on each, covering technical and schedule aspects. Cost is covered in a monthly meeting of division leaders as part of the Laboratory management review. Systems engineering supports these reviews indirectly through studies or analysis.

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Example Use Only

Spec Level	Approval	Review
1	OSSC	ESAAB
2	SSCPO	OSSC
3A	SSCL Project Management	SSCPO
3B	ADOD	SSCL Project Management
4	Technical Divisions* MSD, ASD, CCD	ADOD

Cost Change Approval Authority**

WBS Level	SSCPO	SSCL/PM	ADOD	SSCL Div
0	Any Change in TPC***	None	None	None
1	Less Than $50M or More Than $10M	Less Than $10M or 5%	None	None
2	$5M or More	Less Than 10% or $5M	None	None
3	N/A	More Than 5%	Less Than 5%	None
4	N/A	Receive Report For More Than $1M	More Than 5%****	Less Than 5%
5	N/A	NA	Receive Report For More Than $1M	All****

Schedule Change Approval Authority

Level	Approval Authority
1	OSSC, based on contractual agreement
2	SSCPO, supports achievement of Level 0 Milestones
3A	SSCL Project Management, used to control the project
3B	ADOD
4	Division Head
5	Group Leader or Subcontractor

Figure 3. Reviews.

Trade Studies/Decision Papers

Trade studies will be an important part of the systems engineering process. However, the systems engineering currently emphasizes requirements, definitions, documentation, and specifications. Once specifications are completed and design begins, major emphasis will shift to interfaces and trade studies, which are already being conducted. Most of the studies are related to the machine parameters and are conducted primarily by physicists. These are called "optimization" studies, and they include the machine lattice and specific design parameters. Other major studies relate to the construction aspects, such as building sites and building functions.

Decision papers, signed by the SSCL General Manager, Project Manager, Technical Director, or the Deputy Project Manager, are processed through document control, where they are given a control number and distributed as a released document. In this way decisions can be tracked and people desiring information on a particular decision know where to find it. An example of a decision paper residing in document control is the definition of system availability.

CONCLUSIONS

Clearly, the application of systems engineering is more difficult at the SSCL than in a DOD environment, where the concept of systems engineering is widely accepted. It is not clear, however, that systems engineering is well understood, even at the DOD. If we accept the definition of systems engineering stated earlier in this paper, then there is no clear demarcation of systems engineering principles except for discipline in the process of designing, building, and operating a system. At the SSCL, systems engineers must be creative in applying systems engineering. The environment will not accept strict discipline nor a "cookbook" approach. One recent example comes to mind: An engineering group leader was concerned about controlling engineering drawings, 30 of which were located at the SSCL and the rest at a national laboratory. The group leader was unsure about changes to these drawings or whether he could control the changes. He approached the systems engineering group for help, but made it clear that he did not want configuration management. The systems engineering leader for that division agreed to help with "drawing control," thus avoiding the term configuration control. Maybe the lesson here is that all of the standard configuration management functions are not needed; in this case, only drawing control was called for. Still, the lasting impression is that the systems engineering function, specifically configuration management in this example, is not understood.

Without much elaboration, the lessons learned can be summarized as follows:

1. Cultural differences are real, and they represent a real test. Subcontractors dealing with the SSCL should understand the cultural differences and work very hard on definitions of terms. A misunderstanding of terms could lead to dissatisfaction by both parties.

2. Reaching the proper people is still difficult and time-consuming. A recent layoff at a major aerospace company provided a potential source of people. By job title and resume, many satisfied the criteria for systems engineers and configuration management. However, interviews revealed a very narrow application of systems engineering, and not one had the required ability to interface with various disciplines and to prepare specifications and interface control documents.

3. The new definition of systems engineering now includes attitude. A systems engineer must be positive and have a direction in mind. His education and experience provide the tools to accomplish the mission. His attitude provides the motivation and courage to persevere toward the goal.

4. The most important lesson learned is that systems engineering can be drastically tailored and still be effective. It can be used, as opposed to building plans and specifications that sit on the shelf. A statement attributed to Benjamin Franklin puts it in perspective: "I wrote you a long letter because I didn't have time to write a short one." When members of the systems engineering staff at the SSCL complete their jobs, they will be true systems engineers because they had to be creative in the application of systems engineering.

WHAT SUBCONTRACTORS CAN EXPECT

In summary, subcontractors can expect the following:

- A different culture from DOD contracting and a different understanding of terms.
- Conduct of plans and project management similar to that of DOD contracts due to the on-site presence and influence of DOE.
- Specification formats of Mil-Std-490A for major procurements and other formats for lesser procurements.