DOE National Laboratories Improvement Council's White Paper on Management of Major Research Facility Construction Projects

What is this white paper about?

Research investments by the Department of Energy (DOE) and the National Nuclear Security Administration (NNSA) have yielded a wealth of dividends, including new intellectual capital, significant technological innovations, increased national security, enhanced economic competitiveness, and improved quality of life for the American people. Many of these scientific breakthroughs and societal benefits have been produced by researchers at DOE's National Laboratories, which are often called the "crown jewels" of the U.S. National Research infrastructure.

An essential element contributing to this success is DOE's investment in one-of-a-kind, large-scale research facilities. These facilities often cost hundreds of millions or even billions of dollars and may take many years to complete. Because of the importance of these facilities to the future of DOE's and the nation's research enterprise, the DOE National Laboratories Improvement Council (NLIC) chose to look back at the attributes of success and failure seen in past research facility projects to identify how future projects could be delivered more effectively and efficiently. This white paper is a summary of the lessons learned from a representative set of recent national laboratory projects. Some of these projects were successful, some were not, and all contributed to the attributes captured in this paper.

Who else looked at this topic?

For more than 60 years, DOE and its predecessor agencies have conceived, designed, built, and operated major research and production facilities. Starting with the Manhattan Project, DOE and its predecessors have expected disciplined management of these construction projects. The most current version of these expectations is DOE Order 413.3, "Program and Project Management for the Acquisition of Capital Assets." Because of the size and expense of these projects, they have been closely reviewed by the Administration and Congress. Over the last 15 years, the Administration, Congress, and DOE itself have reviewed the Department's and its contractors' abilities to deliver major system acquisition projects at the quality expected, on schedule, and within budget. These reviews have been performed by the GAO, the National Research Council, the Civil Engineering Research Foundation, and others. The results from these independent assessments have had varying degrees of impact and improvement. The NLIC found these reviews informative and useful in its own evaluation, and it includes relevant conclusions in the lessons learned provided below.

What projects did NLIC consider?

Since the mid-1980's, performance of major research facility construction projects has been mixed. Several high profile, large-budget projects encountered unanticipated challenges requiring significant budget, scope, and schedule adjustments. In some cases these adjustments led to termination of the projects. The problems with these projects caused some observers to conclude that DOE and its contractors lacked the skills needed to adequately manage projects of this size. However, during this same period, there have also been many noteworthy and successful projects that have not received the same public scrutiny. We should continually remind ourselves that by their nature, large science projects are often a delicate balance between high scientific payoff and significant technical risks, frequently long in duration, visible within the budget process, and may require scientific breakthroughs before construction can be completed. For these very same reasons, all projects should be managed while following rigorous project management principles to ensure these types of issues are managed and communicated as early as possible.

Below is a list of selected construction projects, some starting in the mid-1980s, and their final outcomes:

Project	**Laboratory**	**Project Period**	****Cost, $M**	*****NLIC Assessment**
Advanced Photon Source (APS)	ANL	1989-1996	799	Successful
Continuous Electron Beam Accelerator Facility (CEBAF)	Thomas Jefferson Lab	1985-1996	513	Successful
Environmental Molecular Sciences Laboratory (EMSL)	PNNL	1991-1997	230	Successful
B Factory	SLAC	1994-1998	293	Successful
Relativistic Heavy Ion Collider (RHIC)	BNL	1991-1999	617	Successful
US Large Hadron Collider Project (LHC)	Fermilab, BNL, LBNL	1998-2008	531	Successful
Spallation Neutron Source (SNS)	ORNL	1999-2006	1,412	Successful
Neutrinos at the Main Injector (NUMI)	Fermilab	1998-2005	168	Problems/ Successful
Superconducting Super Collider (SSC)	SSC	1990-1999	8,300	Successful Terminated
National Ignition Facility (NIF)	LLNL	1995-2008	3,502	Problems/ Successful
Dual Axis Radiographic Hydro Test Facility (DARHT)	LANL	1998*-2008	270	Problems/ Successful

(* Originally proposed in ’82, stopped in ’90, revised and restarted ’98.)
**The Cost $M baseline cost is the currently approved baseline cost, which may be different from the initial cost estimates.
***The definition of success for completed projects is that the approved scope was delivered within the final approved baseline cost and schedule. For projects in progress, success means that current performance is consistent with the approved baseline parameters.

It is important to note that each of these projects demonstrated a record of safety performance that was exemplary for its time and that they were implemented in accordance with the current management guidelines and lessons learned from previous projects. None of these projects were conducted using the requirements of the recently issued DOE Order 413.3. In fact, there are a very limited number of projects in the DOE pipeline that were initiated under the new Order, and it is premature to measure the impact of DOE Order 413.3 on project performance. The planning criteria for new projects in the new order have improved the selection of projects that go forward. Several projects that met the planning criteria under the new order have been proposed, e.g., Rare Isotope Accelerator (RIA), at ANL; 12 GeV Upgrade, at Thomas Jefferson Lab; Protein Production and Characterization Facility (PPCF), at ANL; Capability Replacement Laboratory (CRL), at PNNL; and the National Synchrotron Light Source Upgrade (NSLS-II) at BNL. Of these, only NSLS-II, 12 GeV Upgrade, and the CRL have continued beyond Critical Decision 0 (CD-0).

In the past several years, DOE and its contractors have taken a number of actions to improve performance. For example, DOE, in its new Order 413.3, requires its own organizations and its contractors to establish certified project management systems and conduct external independent reviews (EIR) of major projects. The Office of Science has been conducting independent reviews of its projects for several years through the Office of Project Assessment, headed by Daniel Lehman. These SC reviews, which pre-date DOE Order 413.3, have been conducted periodically on all large SC construction projects and at facilities where large experimental equipment was being fabricated. These reviews, which have been recognized for the development and implementation of a robust project peer review and evaluation procedure, have consistently had profound impacts on DOE’s large science projects, resulting in the projects being delivered on time and on budget. (The concept of independent reviews has been promoted by the White House Office of Science and Technology Policy as a best practice for all Federal agencies.) Recently, additional independent reviews have been required by the Office of Engineering and Construction Management (OECM) to comply with the new requirements from the Deputy Secretary. These second reviews have not, as yet, been demonstrated to produce more enhanced project management than result from the SC reviews.

What did NLIC observe?

In reviewing these projects, NLIC identified several best practices, derived from factors contributing to both the success and failure of projects. NLIC examined previous DOE and independent review reports, GAO reviews and audits, and material developed for an NLIC meeting on management of construction projects. This meeting included briefings from senior DOE officials and project managers from current major construction projects across the complex. Not surprisingly, NLIC discovered that both successful and unsuccessful projects have common, instructive attributes.

Success Attributes

- **Upfront planning with clear, understandable, well articulated objectives –** Thorough planning is essential to establish solid objectives, scopes, programming, general designs, budget estimates, and risks. Major science projects are extremely complex and often require cutting-edge technologies, which makes developing definite plans difficult. However, it is important to create plans that clearly articulate the scientific value of the facility and key uncertainties to senior management approvers and to affected stakeholders in terms they understand so they can have confidence that the project will be successful prior to approval. Key technical issues need to be identified and solved during the conceptual design phase of the project, and project managers must provide realistic costs and schedules.

- **Top-down management and support from performing contractor –** DOE and its contractors must give priority to the project and provide the best project management team and support resources available. Although this has the potential to compete with ongoing mission work, it clearly demonstrates the necessary commitment from senior management, and recognizes the strategic importance of the major system acquisition.

- **Strong project team with state-of-the-art project management tools –** The contractor must create and empower a fully qualified project team and totally dedicate them to the project. The team must have the skills and tools necessary to optimize project performance and to address the complex technical and management issues that will arise.

- **Consistent and timely funding –** All projects require adequate and stable funding from the beginning to the end. Many expensive, long-duration projects get into trouble from budget uncertainties and delays in funding appropriations. The Administration and Congress can help assure that projects are efficiently executed by committing to full funding at the time the project is authorized, and then appropriate funding (especially in the early years) on the approved schedule baseline.

- **Risk identification and mitigation –** Thorough technical risk assessments and effective plans to mitigate them are essential, and they must be reviewed by both scientific and project management team members. Risk management should start early in the project, ideally at CD-0, and be diligently continued throughout the project's life.

- **Effective baseline change-control process –** All project managers will be faced with baseline changes during the life of the project. Successful projects establish scope, schedule, and budget baselines as early as the conceptualization phase of the project. They maintain focus on project outcomes via baseline change control. This should not be confused with the formality of baseline establishment at Critical Decision 2 (CD-2). The CD-2 baseline is established to meet the routine formal reporting requirements of the Federal system. Effective baseline management extends both before and after these reporting expectations have been met.

- **Adequate contingency (budget and schedule) –** Larger funding contingencies are necessary for complex, start-of-the-art science projects. These contingencies should be proportional to the risks identified, and they must be built into the baseline estimates for inclusion in the Total Project Costs. While this expectation has been articulated in DOE Order 413.3, the practical application of this approach has never been fully realized. Based on approved project risk assessments, realistic (not overly optimistic) budget and schedule contingencies need to be included and approved in the initial project baselines.

- **Regular technical and project management reviews –** Regular reviews help to assess the project's progress towards its objectives and surfaces issues in time to address them in advance, minimizing impacts to the project. Routine reviews also act as an effective communication tool to assure that sponsors gain the necessary information on project progress. Conversely, one failure mode is abdicating overall performance accountability to the process of review. A second failure mode is having redundant reviews, which may divert resources away from delivering project outcomes.

- **Clear and specific partner agreements –** For those projects that involve multiple organizations (e.g., SNS), all project partners must clearly understand the overall objectives of the project and their roles and responsibilities in achieving those objectives. All interfaces must be formally agreed to by the respective parties.

- **Coherent project sponsorship by the Executive Branch and Congress throughout the project's lifecycle –** Given competition for discretionary funding and the fact that major science project investments can take a long time, having strong sponsorship becomes critical to maintaining the project baseline. In the case of SNS, having multiple laboratories and multiple Congressional stakeholders fully committed to the success of the project helped the project maintain momentum during critical periods. This was especially useful as narrowly focused, external independent reviews from various oversight agencies drew conclusions that conflicted with the Department's agenda.

- **Procurement managed within the project –** An integrated procurement team dedicated to the project is important to success. Procurement staff, integrated within the project team, understands the technical requirements, develops long-term relationships with vendors, and understands the ramifications of cost and schedule performance. The project's procurement function should operate under a separately approved project procurement charter, independent from the contractor's main procurement organization, to avoid excessive overhead costs, avoid the operational impacts of contracting officer disputes, and be more responsive to schedule requirements.

Failure Attributes

Obviously, the opposite of the above success attributes can lead to failure. NLIC identified the following failure modes that need to be avoided:

- **Arbitrary funding profile manipulation –** An obvious way to introduce failure to a project is to assume no impact when funding profiles are manipulated. Projects are conducted in a political world and economic situations or events may require redirection of project funds based on competing priorities. The consequences of delayed or reduced funds to major scientific projects require thorough analyses to ensure that the necessary information is available to the decision-makers about the impacts to scope, schedule, and Total Project Costs. With complete plans and modern tools, these analyses are easily performed. The most significant failure is not to have asked the question.
- **Inadequate recognition of project risks –** Active management of a project's baseline involves the prioritization and allocation of funding as well as the intentional reservation of

funding to address uncertainty. Without a disciplined process to identify and understand project risks and realistic plans for mitigating those risks, accurate project plans with realistic schedules and costs captured in the baseline cannot be produced.

- **Significant changes in scope –** Inadequately defined or poorly communicated scope or significant changes in scope without corresponding changes in funding are recurrent causes of project failure. Maintaining scope stability is particularly difficult in science projects where the rate of change in technology is often far greater than the rate of progress of the project. There is often pressure to incorporate the latest technological changes into the project scope, and doing this without providing additional funding can lead to delays in execution or overruns of baseline costs. Development of, and adherence to, a Project Requirements Document (PRD), is essential to avoiding this failure mode. That is, DOE and the contractor should have commitments in place that changes to the established scope will only be made through an approved Change Control Process.

- **Reliance on process definition rather than focus on outcome –** Projects are inherently suited to procedures and process development. However, the recent tendency to expect a rigorous process definition to result in successful project outcomes is not supported by history. Projects are "temporary endeavors to deliver a unique product or outcome." Processes, on the other hand, are defined by "repeatable operational steps." When these two definitions conflict, the recent tendency has been to default to process definitions. This has led to significant time and money being spent on satisfying process steps that have little impact on project success. For example, some process steps with uncertain value include mandated External Independent Reviews, after-the-fact certifications of project management systems, and backtracking to produce critical decision (CD) prerequisites for procedural purposes.

- **One size fits all –** The DOE mission is broad and diverse. The application of project management tools across this portfolio must be customized, as appropriate, to the specific industry, technology, or contractor. Consequently, a one-size-fits-all model cannot realistically apply beyond the broadest levels of performance. Treating all DOE-sponsored projects identically does not represent a best practice.

- **Using projects to solve site operational weaknesses –** It is not useful or appropriate to constrain or delay a project to force operational improvements. The typical result is that the operational improvement occurs and the project fails. Projects in this situation are blamed for cost and schedule impacts driven by scope changes caused by these improvements.

What does NLIC recommend?

DOE and its contractors can learn valuable lessons from the successes and failures of past and current projects. Recent improvements in managing major projects include DOE Order 413.3 and its use of a broad framework for project definition, planning, risk identification, and decision approvals; the focus on building DOE and contract project management skills; the new technical review processes; and increase support from contractor management.

In addition, NLIC recommends the following to improve the process for successful development and completion of projects:

- Perform rigorous and thorough planning, including scope, cost, schedule, risk identification and mitigation, and use of risk-based contingencies.
- Adhere to a rigorous review of candidate projects, and then fully fund the projects selected.
- Use the critical decision process to sharpen and articulate project objectives.
- Endorse and implement the practice of budget range and contingency allocation based on complexity and risks.
- Implement non-redundant project reviews consistent with the project's complexity, risk, and size.
- Leverage existing review protocols to meet Order requirements.
- Support early project baselines and do not institute formal reporting systems until CD-2.
- Empower project directors to eliminate process-driven requirements when there are no corollary benefits to project outcomes.
- Allow a project director to combine review and approval processes based on the size and complexity of a particular project (graded approach).
- Separate project outcomes from the program approach in all areas of operations, safety, technology, and metrics, clarifying the distinction between the project role and the operational role.