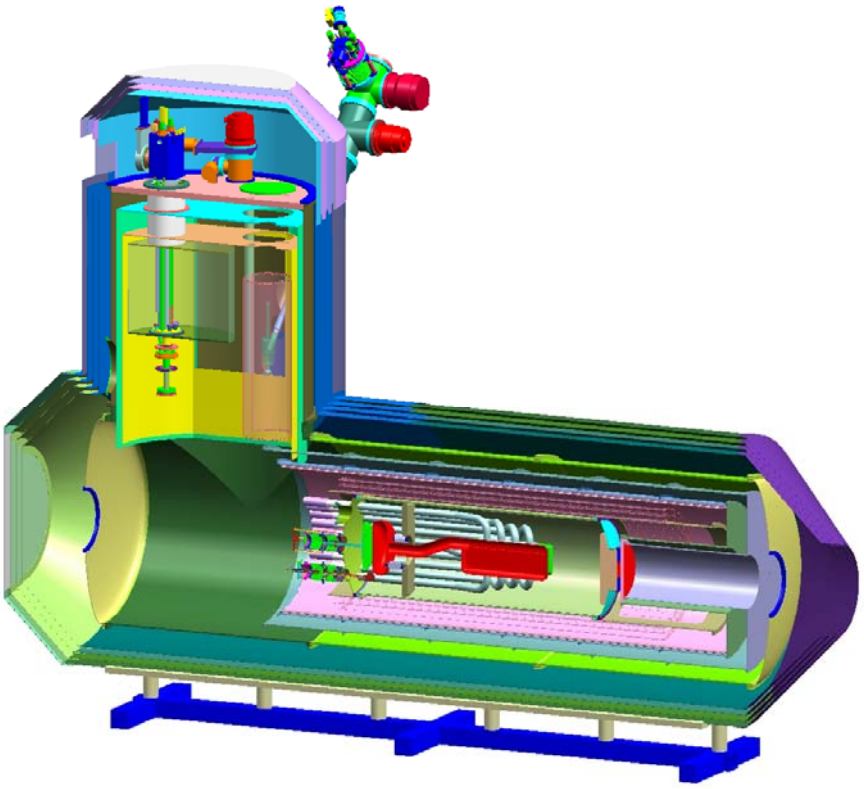
# Preliminary Project Execution Plan for the Electric Dipole Moment (EDM) of the Neutron Project



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# Preliminary Project Execution Plan

## Project #MIE-06-EDM
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# In Search of the Electric Dipole Moment (EDM) of the Neutron

# Preliminary Project Execution Plan

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## List of Acronyms and Abbreviations

| | |
|---|---|
| AE | acquisition executive |
| ANSI | American National Standards Institute |
| BA | budget authority |
| BCP | baseline change proposal |
| CAD | computer aided design |
| CCB | change control board |
| CD | critical decision |
| CDR | Conceptual Design Report |
| CDS | central detector systems |
| CF | conventional facilities |
| CP | charge parity |
| CPM | Contractor Project Manager |
| D&D | decommissioning and decontamination |
| DAQ | data acquisition |
| DCD | design criteria document |
| ORO | Oak Ridge Site Office (DOE) |
| DOE | Department of Energy |
| EA | environmental assessment |
| EAC | estimate at completion |
| EDM | electric dipole moment |
| EIS | environmental impact statement |
| ESAAB | Energy Systems Acquisition Advisory Board |
| ESH&Q | environment safety, security and health |
| ETC | estimate to complete |
| EVMS | earned value management system |
| FNPB | Fundamental Neutron Physics Beamline |
| FONSI | finding of no significant impact |
| FPD | Federal Project Director |
| FTE | full time equivalent employees |
| FY | fiscal year |
| He3S | $^3$He Services |
| HQ | DOE Headquarters |
| HV | high voltage |
| IPT | integrated project team |
| ISMS | integrated safety management system |
| LANL | Los Alamos National Laboratory |
| LANS | Los Alamos National Security, LLC |
| LASO | Los Alamos Site Office (DOE) |
| LHe | liquid helium |
| LLP | long lead procurement |
| M&O | managing and operating |
| MIE | major item of equipment |
| nEDM | electric dipole moment of the neutron |
| NEPA | National Environmental Policy Act |
| NNSA | National Nuclear Safety Administration |
| NOI | EIS Notice of Intent |
| NP | Office of Nuclear Physics (DOE) |
| NPAC | Nuclear Physics Advisory Committee |
| NSF | National Science Foundation |
| OP | funding type – operating expense |
| OPA | Office of Project Assessment (DOE) |
| OPC | other project cost |
| ORNL | Oak Ridge National Laboratory |
| PARS | Project Assessment and Reporting System (DOE) |
| PCR | project change request |
| PEP | project execution plan (federal document) |
| PPEP | preliminary PEP (contractor document) |
| PSAR | Preliminary Safety Assessment Report |
| PSO | Program Secretarial Officer |
| QA | quality assurance |
| R&D | research and development |
| RF | radio frequency |
| ROD | EIS record of decision |
| SAD | safety assessment document |
| SAE | Secretarial Acquisition Executive |
| SAR | safety analysis report |
| SC | Office of Science (DOE) |
| SC-NP | DOE Office of Science, Office of Nuclear Physics |
| SDB | small/disadvantaged businesses |
| SNS | Spallation Neutron Source |
| TAT | Technical Advisory Team |
| TEC | total estimated cost |
| TPC | total project cost |
| U.S. | United States |
| UCN | ultracold neutron |
| VE | value engineering |
| WBS | work breakdown structure |

# Electric Dipole Moment (EDM) of the Neutron

# Preliminary Project Execution Plan

## 1. Introduction

The neutron EDM (nEDM) experiment studies the fundamental space-time properties of the neutron, one of the building blocks of the matter that surrounds us. This is done by looking for a very small difference in the precession rate of a neutron placed in magnetic and electric fields when the electric field is oriented either "up" or "down." Precession is a phenomenon by which the axis of a spinning object "wobbles" when a torque is applied to it. The observation of a different precession rate indicates that the neutron has a significant electric dipole moment and, therefore, a charge-parity (*CP*)-violating preferred arrangement of the quark charges inside the neutron. *CP*-violation may explain the matter excess in the universe. The proposed major item of equipment (MIE) in support of this experiment will allow the fundamental space-time properties of the neutron to be studied with two orders of magnitude greater sensitivity than ever before. This level of sensitivity does not exist in current and planned experiments and is necessary in order to measure the different rates of precession to sufficient accuracy to constrain existing theoretical models.

The experimental apparatus is being proposed by Los Alamos National Laboratory (LANL), and involves collaborators from Oak Ridge National Laboratory (ORNL) and thirteen universities. The item will be located at the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source (SNS) Facility at ORNL. FNPB is unique in that it will provide the highest peak current of cold and ultracold neutrons (UCN) in the world. The FNPB is under fabrication with support from the Office of Nuclear Physics and is scheduled to be complete in 2010.

The collaboration will be supported by the following Department of Energy (DOE) and National Science Foundation (NSF)-supported universities:

- Arizona State University,
- University of California at Berkeley,
- California Institute of Technology,
- Duke University,
- Hahn-Meitner Institut,
- Indiana University,
- University of Illinois-Urbana-Champaign,
- University of Kentucky,
- Massachusetts Institute of Technology,
- North Carolina State University,
- Simon-Frasier University,
- University of Tennessee, and
- Yale University.

On November 11, 2005 Raymond L. Orbach approved the statement of Mission Need for the nEDM experiment with a total project cost (TPC) range of $12.0M to $18.3M. The approval also designated the Associate Director for Nuclear Physics as the Acquisition Executive for this project with authority to approve all subsequent critical decisions.

This Preliminary Project Execution Plan (PPEP) for the EDM Project provides overall guidance to the various project participants on the roles, responsibilities, and management interactions among the DOE Office of Science (SC), the DOE Los Alamos Site Office (LASO), the national laboratories, and the universities involved in the EDM Project. The PPEP describes the coordination of efforts of the project team, including the processes and procedures used by the EDM Contractor Project Manager (CPM) and Federal Project Director (FPD) to ensure that the project is completed on time and within budget. The PPEP defines the project scope and the organizational framework, identifies roles and responsibilities of contributors, and presents the work breakdown structure (WBS) and schedule. The EDM PPEP also describes the formal change control process by which project cost, schedule, or scope may be revised in consultation with the FPD and the DOE Office of Science, Office of Nuclear Physics (SC-NP).

The EDM PPEP also invokes a separate Project Controls Manual as the reference procedure for implementation of all estimating, budgeting, planning, and scheduling activities on the EDM Project.

# 2. Mission Need and Justification

The mission of the Nuclear Physics (NP) Program is to foster fundamental research in nuclear physics that will provide new insights; advance our knowledge on the nature of matter and energy; and develop the scientific knowledge, technologies, and trained manpower that are needed to underpin the DOE's missions for nuclear-related national security, energy, and environmental quality. To accomplish this mission, the Program supports the research of scientists, the operations of facilities and the development of forefront facilities and technology. These activities are carried out under the mandate provided in Public Law 95-91 that established the DOE, and assigns the NP Program the lead responsibility for federal support of fundamental research in nuclear physics.

EDM provides research capabilities that directly support the NP mission and address the NP Program Goal 05.20.00.00 to understand the evolution and structure of nuclear matter from the smallest building blocks, quarks and gluons, to the elements in the universe created by stars. A main objective of this field is studying fundamental symmetry properties in nuclear systems. The EDM experiment supports this goal by studying the fundamental space-time properties of the neutron, one of the building blocks of the matter that surrounds us.

The DOE's Strategic Plan identifies five Strategic Themes (one each for nuclear, energy, science, management, and environmental aspects of the mission) plus seventeen Strategic Goals that tie to the Strategic Themes. The EDM Project supports the following goals:

- **Strategic Theme 3**, Scientific Discovery
- **Strategic Goal 3.1**, Scientific Discovery: Achieve the major scientific discoveries that will drive U.S. competitiveness; inspire America; and revolutionize our approaches to the Nation's energy, national security, and environmental quality challenges.
- **Strategic Goal 3.2**, Foundations of Science: Deliver the scientific facilities, train the next generation of scientists and engineers, and provide the laboratory infrastructure required for U.S. scientific primacy.

The possible existence of a nonzero EDM of the neutron is of great fundamental interest in itself and directly impacts our understanding of the nature of electroweak and strong interactions. The experimental search for this moment has the potential to reveal new sources of temperature (*T*-) and *CP*-violation and to challenge calculations that propose extensions to the Standard Model. In addition, the small value for the nEDM continues to raise the issue of why the strength of the *CP*-violating terms in the strong Lagrangian are so small. This result seems to suggest the existence of a new fundamental symmetry that blocks the strong *CP*-violating processes.

The existence of an nEDM constrains a wide variety of theories of nuclear and particle physics. The EDM Project will search for new physics in the *CP*-violating sector with a sensitivity of $0.3 \times 10^{-28}$ $e\oplus$cm. The increased sensitivity will permit researchers to achieve greater precision measurements in order to probe *CP*-violation in the strong interaction at sufficient levels needed to help understand the matter/antimatter asymmetry of the universe.

## 2.1 Project Goals

The goal of the current experiment is to significantly improve the measurement sensitivity to the nEDM over what is reported in the literature. The experiment has the potential

- to measure the magnitude of the nEDM or
- to lower the current experimental limit by one to two orders of magnitude.

Achieving these objectives will have major impact on the understanding of the physics of both weak and strong interactions.

# 3. Project Description

The figure of merit for EDM experiments is proportional to the strength of the electric field multiplied by the square root of the number of neutrons and the time they are exposed to the electric field. This EDM experiment improves on all three of these quantities by taking advantage of the special properties of liquid helium (LHe) with an expected improvement of two orders of magnitude in sensitivity over existing experiments. UCN are produced in the LHe by employing the superthermal method where very high densities of UCN are produced in an experimental bottle by down-scattering cold neutrons from helium atoms, resulting in a UCN and a phonon. LHe is a very good dielectric, permitting the application very high electric fields to the measurement volume. The cryogenic temperatures will allow for long storage, and, thereby, measuring times of the UCN. This method is currently the only experimental approach being proposed in the U.S.

The EDM experiment looks for a very small change in the precession rate of a neutron placed in a weak magnetic and a strong electric field when the electric field is oriented "up" or "down." Thus, the experiment is extremely sensitive to small fluctuations of the external magnetic field that envelops the UCN. This problem is overcome by the addition of the only other species that can occupy the same volume as the UCN (i.e., $^3$He) which has a magnetic moment very similar to that of the neutron but can have no EDM at the sensitivity of the experiment. Thus, the $^3$He provides a control measurement for the neutrons. The $^3$He provides the extra benefit of measuring the precession rate of the neutrons through their highly spin-dependent capture cross section.

The experiment is based on the magnetic-resonance technique of rotating a magnetic dipole moment in a magnetic field. The technical approach is based on a new method to make a precision measurement of the neutron precession frequency under the influence of an electric field. The strategy features

- using a dilute mixture of polarized $^3$He in superfluid $^4$He as a working medium for the very high electric field environment;
- determining in situ the magnetic field experienced by the neutrons, using a direct SQUID measurement of the precession frequency of the $^3$He magnetic dipoles; and, finally,
- making a comparison measurement of changes in the precession frequency, under E field reversal, of the neutron and $^3$He components of the fluid, where the neutral $^3$He atom does not have an EDM.

The EDM experiment will have eight principal elements comprising the technical scope

1. polarized neutron beam line and shielding;
2. cryostats, refrigerators and related equipment;
3. helium three systems;
4. magnets and magnetic shielding;
5. central detector systems (CDS),
6. electronics, computers, simulations, and data analysis;
7. infrastructure in support of the cryogenic apparatus and for assembly of the components; and
8. final assembly and integration.

Descriptions of these components can be found in Section 4.2.

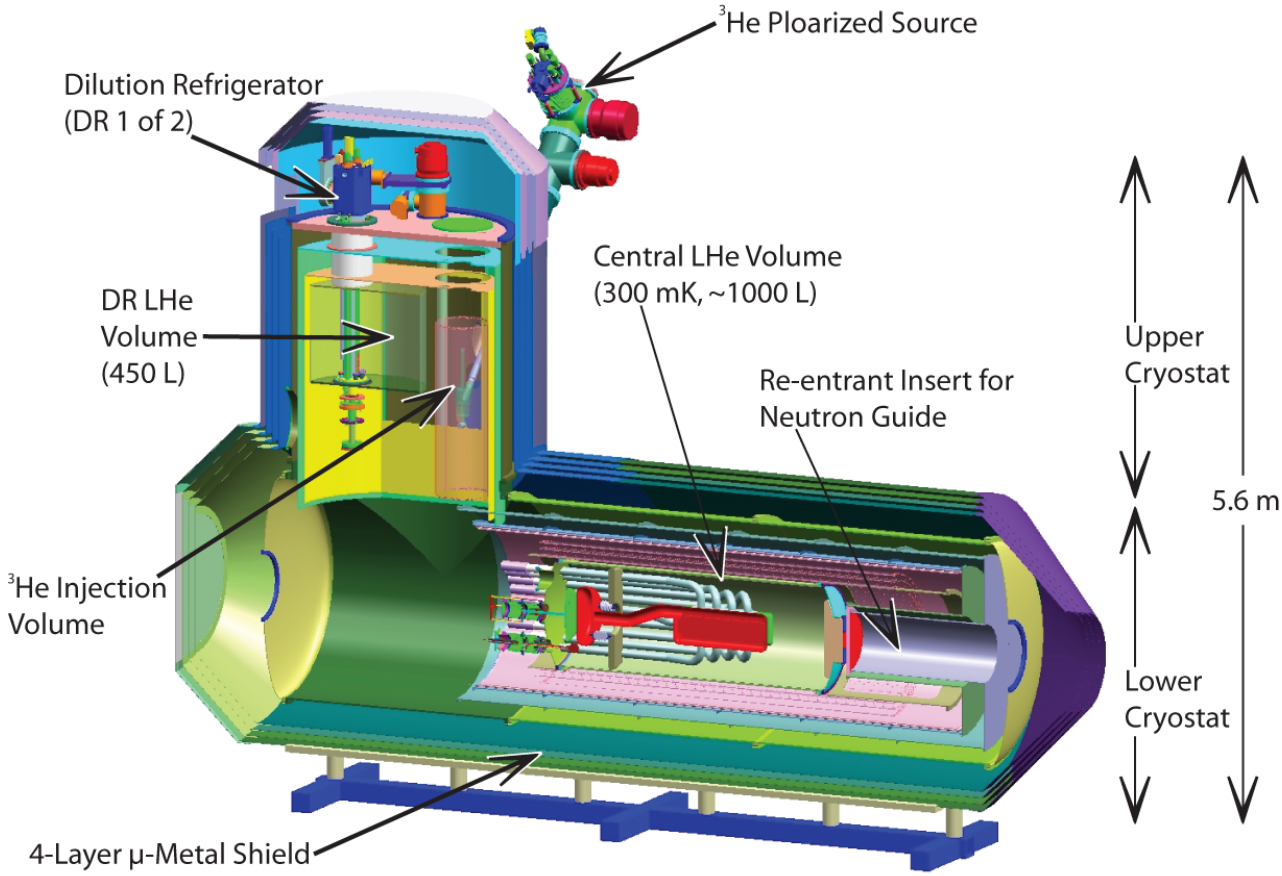


**Figure 1.** Schematic diagram of nEDM apparatus.

Without an EDM experiment, the opportunity to play this leadership role in achieving the necessary measurements to better understand the space-time properties of the neutron (in support of NP's mission) will be lost. In addition, the return of investment in the FNPB and the scientific benefits anticipated with its construction will be minimized. Alternatives would include doing nothing and not realizing this compelling scientific opportunity, or playing a minor role in existing efforts elsewhere in the world, that do not have the capabilities of the FNPB at the SNS, or the projected sensitivities of the proposed experimental technique.

This nEDM experiment is designed to be the most sensitive of any experiment to testing for physics beyond the Standard Model of electroweak interactions. The experiment has the exciting possibility for a major discovery that will shed light on theories such as supersymmetry and the origins of the matter/antimatter asymmetry in the universe. Of all experiments in the world on the nEDM, it has the best chance for discovery because of its use of the $^3$He comagnetometer to control systematic errors. It measures a different part of the time-reversal-violating phenomena from electron EDM explorations (e.g. it is sensitive to strong interaction effects of great interest that are currently not understood). The result also provides independent information from EDMs in diamagnetic atoms, which at the current time cannot compete with the results expected from this EDM Project. Due to a more favorable dependence on the masses of virtual particles, the nEDM has greater discovery potential than other processes like rare decays of mesons. The conclusion is that the nEDM experiment provides a unique potential for gaining an understanding of new physical phenomena in the electroweak arena.

## 3.1 Technical Scope and Deliverables

The technical scope of the project is the following activities or procurements:

1. construction of the polarized beamline and shielding for the beamline and experiment;
2. construction of the cryogenic vessel and all associated services;
3. construction of the
   (a) $^3$He source and injection system,
   (b) the helium purifier, and all
   (c) valves that control the state of the system;
4. construction of all required magnets and magnetic shields;
5. construction of the
   (a) measurement cells,
   (b) high-voltage (HV) system,
   (c) SQUID (superconducting quantum interference device) detectors, and
   (d) light-detection systems in the central region;
6. installation of all needed support services and production of assembly equipment;
7. development of all required electronics for both data acquisition and slow controls as well as computer systems for data acquisition and analysis, and
8. assembly of the apparatus at the FNPB.

The DOE deliverables are complete when all the items listed above have been procured or fabricated and installed at the FNPB; and the CD-4 requirements identified below have been verified:

- Operate the HV multiplier at 500 mK in the fully assembled apparatus at ORNL.
- Observe the decaying oscillatory signal from polarized UCN captures on polarized $^3$He.
- Observe the decaying oscillatory signal from the SQUIDS of the $^3$He magnetization.

The attainment of these three CD-4 requirements will demonstrate that all of the crucial functions of the apparatus work at a level where there is a reasonable probability that the scientific goals of the project will be reached.

# 4. Management Systems

## 4.1 Organization and Responsibilities

A schematic representation of the management arrangement is shown in Figure 4.1. The solid lines represent the lines of authority from the Contract Project Manager up through the DOE Program Manager, and the dotted lines indicate where communication, coordination, and support are required.

### 4.1.1 DOE

Within the DOE-SC, the Office of Nuclear Physics (SC-26) has overall DOE responsibility for the EDM Project.

### 4.1.2 Responsibilities

The Acquisition Executive is Dennis Kovar, Associate Director of the Office of Science for Nuclear Physics (SC-26). As such, for the EDM Project, he has full responsibility for project planning and execution and for establishing broad policies and requirements for achieving project goals. Specific responsibilities for the EDM Project include

- chairs the ESAAB (Energy Systems Acquisition Advisory Board) equivalent board,
- approves Critical Decisions and Level-1 baseline changes,
- approves the Project Execution Plan,

- delegates approval authority for Level-2 baseline changes to the Federal Project Director,
- conducts Quarterly Project Reviews, and
- ensures Independent Project Reviews are conducted.

The Office of Nuclear Physics (SC-26.2) is responsible for planning, constructing, and operating scientific instrumentation to provide special scientific and research capabilities to serve the needs of U.S. universities, industry, and private and Federal laboratories. Within NP, the Facilities and Project Management Division (SC-26.2) has direct responsibility for providing funding, and programmatic guidance to the EDM Project. The EDM Program Manager, in SC-26.2, is the primary point of contact with the following responsibilities:

- oversees development of project definition, scope, and budget;
- prepares, defends, and provides project budget with support from the field organizations;
- function as DOE HQ's point-of-contact for project matters;
- oversee project progress and help organize reviews as necessary;
- ensure ESH&Q requirements are implemented by the project;
- coordinate with other SC staff offices, HQ program offices, and the Office of Project Assessment (OPA) as needed to execute the project; and
- control changes to project baselines in accordance with this PPEP.

Jehanne Simon-Gillo is the Federal EDM Program Manager.

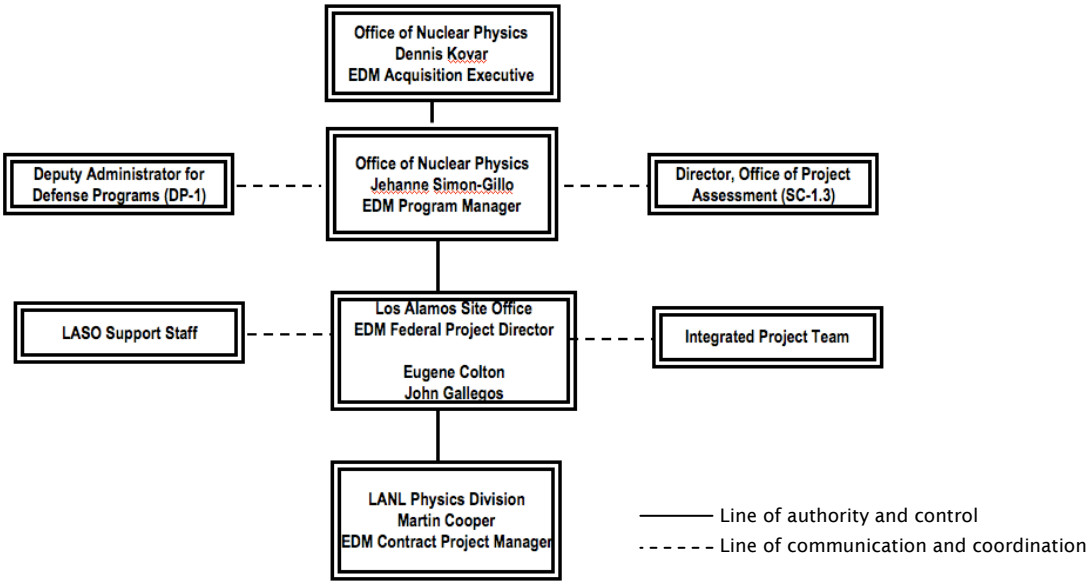


**Figure 2.** DOE organization for the management of the EDM MIE.

Eugene Colton at the DOE Los Alamos Site Office (LASO) is assigned as the Federal Project Director. The Federal Project Director responsibilities include

- ensuring that the contractor designs and constructs a major item of equipment that meets mission requirements;
- providing day-to-day oversight of the project and provide direction to ensure its timely execution;
- functioning as the DOE field point of contact for the EDM Project;
- leading and managing all Integrated Project Team (IPT) matters requiring coordination with LASO;
- maintaining effective communications among SC-NP, LASO, and the EDM Project;
- monitoring, reviewing, evaluating, and reporting on the performance of the EDM Project against established technical-, cost-, and schedule-performance baselines;

- participating in Project Reviews conducted by the EDM Project and by DOE HQ;
- ensuring that the project complies with applicable environmental, safety, security, & health requirements;
- issuing Project Directives to authorize work within funding levels provided in approved Financial Plan Changes;
- authorizing use of EDM Project contingency in accordance with the levels described in this PPEP;
- submitting key EDM Project documents to SC-NP for concurrence/approval;
- reporting progress and update EDM Project data in the DOE Project Assessment and Reporting System (PARS);
- maintaining cognizance of EDM Project activities, anticipating potential problems, and taking corrective actions to minimize project impacts;
- controlling changes within established authority to EDM Project baselines and seek DOE HQ approval for changes beyond the Federal Project Director's authority; and
- performing other functions described for the Federal Project Director in the Project Management for the Acquisition of Capital Assets Manual (DOE M 413.3-1).

### 4.1.3 LANL Physics Division Leader

Funding for the EDM Project will be directed through the LANL Physics Division. Thus, LANL line management will have ultimate fiscal and management responsibility for the construction of the EDM Project. In summary, the CPM, Martin Cooper, reports to the LANL Physics Division Leader, Jack Shlachter.

### 4.1.4 EDM Contract Project Manager

The EDM CPM will implement the EDM Project through the managing and operating (M&O) contractor for LANL, currently the Los Alamos National Security, LLC (LANS), which will be responsible for overall project coordination, execution, and eventual equipment operation. The EDM CPM will report to the LANL Physics Division Leader. The EDM CPM will be responsible for the overall successful execution of the EDM Project, including

- executive-level management of the design, construction, and transition to operations of the EDM Project equipment to ensure all mission requirements are fulfilled in a safe, cost-efficient, and environmentally responsible manner;
- exercise full financial authority and accountability as delegated by DOE and the LANS, LLC, to develop budgets and control EDM Project work within approved baselines, and control changes to approved baselines in accordance with established configuration-management procedures;
- manage and direct procurements within the authority delegated by DOE and the LANS, LLC, including the authority to execute and deliver contracts, agreements, teaming agreements, purchase orders, assignments, and instruments and documents of any kind relating to the acquisition, sale, or disposition of products, services, materials, supplies, and equipment relating to and necessary and desirable for completion of the EDM Project;
- overall responsibility to recruit and manage the human resources necessary to complete the EDM Project and ensure an effective transition to operations, including the overall responsibility for managing the human-resources systems within the authority delegated by DOE;
- maintain relationships with the international scientific communities which are designing and pursuing similar neutron experiments, to keep informed of current progress and developments of potential significance to the EDM;
- manages day-to-day execution in accordance with requirements, procedures, and standards, as set forth in the LANL M&O contract
- integrate fully with collaboration and ORNL to ensure that all interfaces are planned and executed; and
- ensure safety and security are studied and integrated into the design and construction.

Martin Cooper is the EDM Contract Project Manager.

### 4.1.5 Agreements

An agreement between DOE/NNSA LASO and the DOE ORO (Oak Ridge Site Office) will need to be established to ensure good communications, efficient administrative support, and contractor accountability for performing EDM Project work. *(Recommended completion by CD-2*).

Before CD-2, a Memorandum of Understanding will be generated between LANL and other institutions collaborating on the EDM Project.

### 4.1.6 EDM Integrated Project Team

The EDM Project proposes an IPT that consists of core members who are the Federal Project Director, the EDM CPM, and the DOE Program Manager before CD-1. The proposed IPT is led and organized by the Federal Project Director. The IPT will additionally consist of the necessary technical and support personnel responsible for the early planning and description of the EDM Project (see Table 4-1).

**Table 4-1. EDM Integrated Project Team**

| Functional Area | Name | Location/Organization |
|---|---|---|
| **Federal Project Director** | Eugene Colton | Los Alamos/LASO |
| **Deputy FPD** | John Gallegos | Los Alamos/LASO |
| **Program Manager** | Jehanne Simon-Gillo | Germantown/SC |
| **Science Program Manager** | Gene Henry | Germantown/SC |
| **Industrial Safety & Health** | John Pearson | Oak Ridge/ORO |
| **Contract/Acquisition Support** | Caroline Crooks | Los Alamos/LASO |
| **NEPA Support** | Mark Belvin | Oak Ridge/ORO |
| **Quality Assurance** | Dave Rosine | Oak Ridge/ORO |
| **Fire Protection** | Patrick Smith | Oak Ridge/ORO |
| **Site Representative** | David Arakawa | Oak Ridge/ORO |
| **LANL Contract Project Manager** | Martin Cooper | Los Alamos/P-25 |
| **LANL Chief Engineer** | Jan Boissevain | Los Alamos/P-25 |
| **LANL ESSH Lead** | P-25 Safety Officer | Los Alamos/P-25 |
| **Technical Coordinator** | Paul Huffman | Los Alamos/P-25 |
| **ORNL Operations Manager** | Vince Cianciolo | Oak Ridge/ORNL |
| **FNPB Scientific Director** | Geoff Greene | Oak Ridge/ORNL |

The IPT may also includes other essential members of the EDM Project organization, and is shown in Figure 3, below.

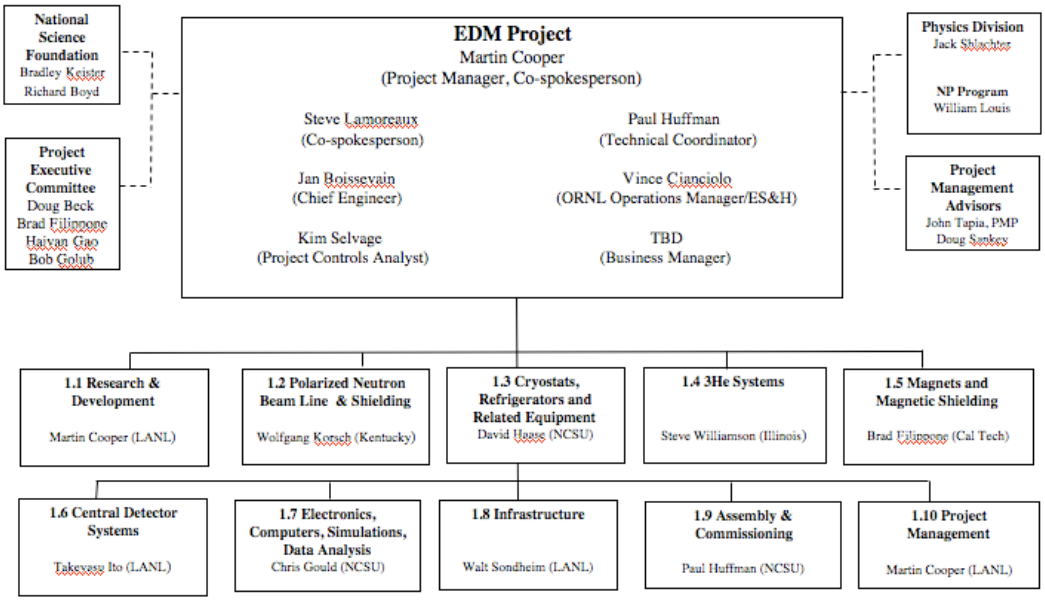


**Figure 3.** EDM Project organization

## 4.2 Work Breakdown Structure

The EDM Project has been organized into a WBS (work breakdown structure). The WBS contains a complete definition of the project's scope and forms the basis for planning, executing, and controlling project activities. The EDM Project WBS is shown in Figure 4. Elements are defined as specific subsystems/deliverables

- research and development (R&D) activities (WBS 1.1),
- polarized neutron beam line and shielding (WBS 1.2),
- cryostats, refrigerators, and related equipment (WBS 1.3),
- $^3$He systems (WBS 1.4),
- magnets and magnetic shielding (WBS 1.5),
- CDS (central detector systems) (WBS 1.6),
- electronics, computers, simulations, and data analysis (WBS 1.7),
- infrastructure (WBS 1.8),
- assembly and commissioning (WBS 1.9), and
- project management (WBS 1.10) [which will also include EDM Project contingency management].

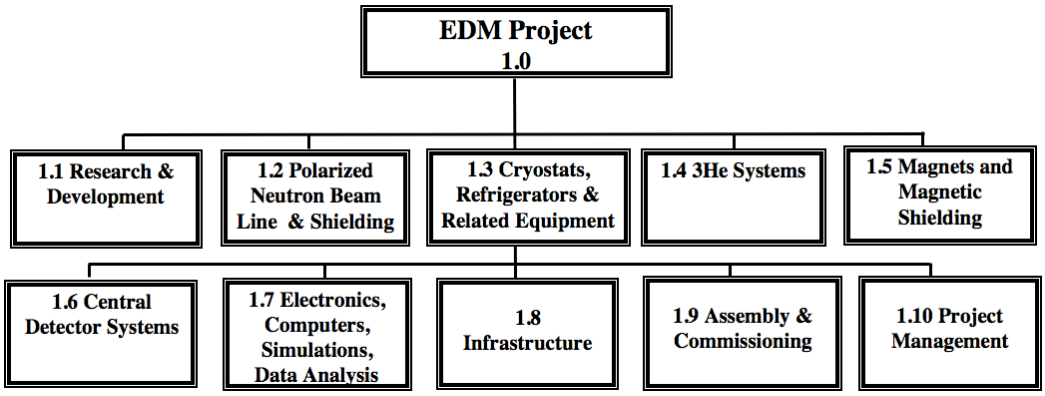


**Figure 4.** The WBS for the EDM Project

### 4.2.1 WBS 1.1 R&D

The R&D program is the experimental verification of the techniques proposed to execute the EDM experiment. R&D efforts started in 1997 and is scheduled to conclude at the end of calendar year 2007. The main goals of the R&D effort are to

- undertake research to understand the physics involved in the experiment,
- experimentally demonstrate that the intended ideas are feasible and meet design specifications,
- select one of several competing techniques, and
- develop method of construction.

The current funding is a mixture of EDM Project funds and LANL LDRD. Additional information on the R&D effort is located in the *WBS Descriptors* document.

### 4.2.2 WBS 1.2 Polarized Neutron Beam Line and Shielding

This subsystem covers the neutronics for the EDM experiment. Neutronics refers to all aspects of the neutron beam-transport system including neutron guides, choppers, secondary shutters, monitors, polarizers, and beam stops, as well as the mechanisms and supports associated with them. The scope of this work package is to maximize the flux and polarization of the neutrons in the target cell. Neutrons will be transported from monochromators of the FPNB to the target using a newly designed neutron guide. The EDM Collaboration is responsible for the last ~15 m of the guide. A neutron polarizer will be incorporated in this last part of the beamline. In order to maintain the polarization a weak magnetic guide field (few Gauss) is needed. It is expected that this field will have to be applied over several meters along the beamline. The neutron beam needs to be split to fill both target cells uniformly with neutrons. A special beamsplitter will be constructed for this purpose. The neutrons will leave the guide in two separate channels. Each channel will have to be equipped with separate radio-frequency (RF) spin flippers to manipulate the spins in such a way that proper spin directions are guaranteed inside the target. The magnetic guide field between the spin flipper and the target will be designed in such a way that it matches the constraints of the target field.

### 4.2.3 WBS 1.3 Cryostats, Refrigerators, and Related Equipment

The purpose of this task is to design, procure, test, and install a device that will enclose the nEDM experimental apparatus at cryogenic operating temperatures for times sufficient to complete the anticipated measurements. The cryovessel will include ports, feedthroughs and pumping lines necessary to connect to the experimental apparatus from room temperature. In addition, the task includes the design, procurement, testing, and installation of the large container that will hold the LHe used to electrically insulate the measurement cells.

### 4.2.4 WBS 1.4 $^3$Helium Systems

The $^3$He Services (He3S) Subsystem is responsible for the management and control of purified liquid $^4$He and polarized $^3$He during the measurement cycle. The block diagram in the *WBS Dictionary* book illustrates the major components of this subsystem. The bulk of this apparatus consists of custom-built, one-of-a-kind items. Special materials will be used that are chosen to be nonmagnetic, nonsuperconducting, $^3$He "friendly" and not readily activated by neutrons. The materials requirements and lack of off-the-shelf components imply that a large engineering effort will be required. These items will be separately tested to check the purification, $^3$He injection, and pressurization functions. Subsequently, a final test of the performance the full system will be carried out. Also included in the scope of this subsystem is the refurbishment and instrumentation of a bulk helium purifier based on the McClintock "heat flush" mechanism.

### 4.2.5 WBS 1.5 Magnets and Magnetic Shielding

This WBS element includes the design, procurement, testing, and installation of the magnets and magnetic shields onto the apparatus. The entire experiment (both the upper and lower cryostat) will be enclosed within a cylindrical four-layer μ-metal magnetic shielding structure held at room temperature. The proposed shields are very large with the largest cylinder having a diameter and length of ~8 ft and ~21 ft, respectively. Residual

magnetic fields penetrating the four-layer conventional (μ-metal) magnetic shielding structure will be expelled by a cylindrical superconducting lead shield mounted in between the 4 K shield for the cryostat and the inner 4 K ferromagnetic shield. Additional details are found in the *WBS Descriptors* book.

### 4.2.6 WBS 1.6 Central Detector Systems

The CDS includes

- the measurement cells and the $^3$He valves;
- the scintillation-light transport and detection system;
- the SQUID magnetometers;
- the beam stop and neutron shield; and
- the HV electrodes, HV generating system, and HV monitoring system.

The scope of this subsystem includes the design, procurement, and installation of the above subcomponents. Also, constructing appropriate apparatus to conduct tests of these subcomponents and performing the tests itself are also part of the scope of the subsystem.

### 4.2.7 WBS 1.7 Electronics, Computers, Simulations, and Data Analysis

This WBS element comprises four work packages

- to develop a slow-controls system for the EDM apparatus;
- to develop a data-acquisition (DAQ) system for the EDM experiment;
- to carry out simulations of all aspects of the experiment; and
- to develop analysis codes to process the large amounts of data obtained over the multiyear duration of the experiment.

### 4.2.8 WBS 1.8 Infrastructure

The infrastructure construction of the EDM Project is concerned with the integration of the EDM experimental apparatus into the EDM experimental hall at the SNS facility at ORNL. This will cover the services to the experimental equipment, such as electrical, plumbing, gas, as well as the fabrication of mechanical platforms to allow for safe access to the experimental equipment. This section also includes designing and fabrication of jigs and fixtures for the experiment, these will allow for the installation as well as maintenance of the equipment. The last task included is the procurement and installation of a counting house facility in the EDM experimental hall.

### 4.2.9 WBS 1.9 Integration and Commissioning

The purpose of this element is to bring together the tested components from the other work packages (Cryostat, Insert, $^3$He Components, Coil Package and Magnetic Shields, and DAQ) and assemble them together to form a complete apparatus.

### 4.2.10 WBS 1.10 Project Management and Support

The management and support functions required to integrate, manage, and deliver the baseline performance outcomes for the EDM Project. This includes the necessary NEPA (National Environmental Protection Act), communications, and reporting functions for the EDM Project.

### 4.2.11 Project Contingency Management

The actions necessary to maintain a risk-based contingency profile, manage the use of contingency as a project baseline element, and deliver the reporting and communication of project contingency as a management function are included in this WBS element.

## 4.3 Acquisition Strategy

The LANS, LLC is the new M&O contractor for LANL. As such, the EDM Project will be managed through LANS, and contracts with the universities as appropriate. The EDM Project will make use of existing staff and facilities from the collaboration, and the FPD, working with DOE-ORO will ensure the installation is carefully coordinated with other research activities at the ORNL.

Project activities will be accomplished to the extent feasible using fixed-priced subcontractors selected on the basis of best value, price, and other factors. Details are provided in the *EDM Acquisition Strategy* document.

Design and equipment-fabrication activities will be accomplished to the greatest extent possible by fixed-price commercially provided services, fabrication services, and specialty engineering services. Where design or equipment-fabrication activities are not commercially available, or not practical due to schedule constraints or technology-transfer limitations, the EDM Project will conduct the design using the best available internal resources or resources of other national laboratories and universities.

Efforts will be made to encourage participation of females, minorities, and small/disadvantaged businesses (SDB) in execution of the EDM Project.

## 4.4 Preliminary Project Schedule

A preliminary Level 0 milestone schedule to construct the EDM experimental apparatus is shown in Table 4-1.

### Table 4-1. Preliminary Level 0 Milestone Schedule

| Major Milestone Events | Preliminary Schedule (CD-0) | Forecast Schedule (CD-1 Basis) |
|---|---|---|
| **0-1. CD-0 (Approve Mission Need)** | Qtr 1, 2006 | Qtr 1, 2006 |
| **0-1b. CD-1 (Approve Alt. Selection and Cost Range)** | Qtr 1, 2007 | Qtr 1, 2007 |
| **0-2a. CD-2a (Approve Long-lead Procurement Budget)** | Qtr 3, 2007 | Qtr 3, 2007 |
| **0-2b. CD-2b (Approve Performance Baseline)** | Qtr 3, 2008 | Qtr 3, 2008 |
| **0-3a. CD-3a (Approve Start of Long-lead Procurement)** | Qtr 3, 2007 | Qtr 3, 2007 |
| **0-3b. CD-3b (Approve Start of Construction)** | Qtr 1, 2009 | Qtr 1, 2009 |
| **0-4. CD-4 (Approve Start of Operations)** | Qtr 2, 2012 | Qtr 4, 2014 |

In addition, the preliminary Level 2 and 3 milestones are shown in Figure 5.

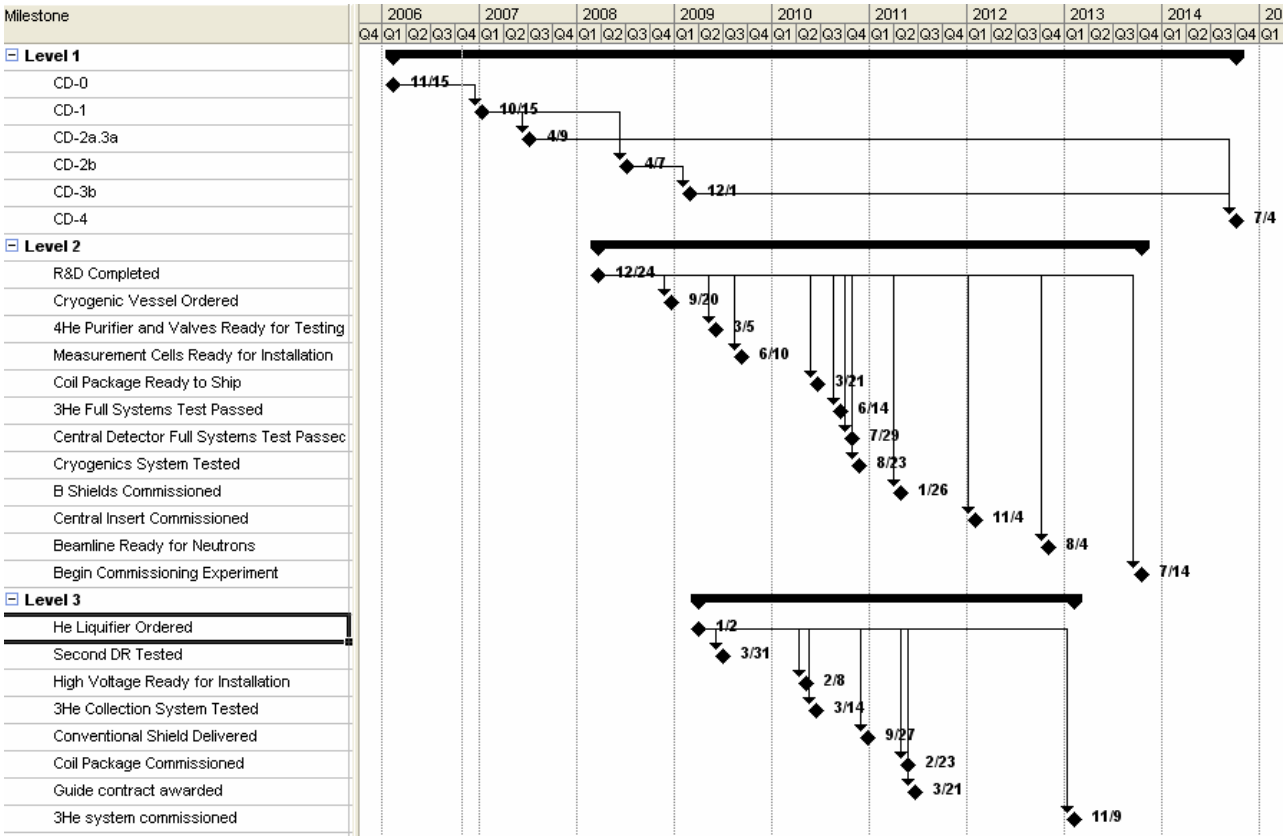


**Figure 5.** Preliminary Level 2 and 3 milestones

## 4.5 Financial Management

### 4.5.1 Cost Estimate by WBS

The recommended preliminary cost range is between $15M–$18.3M. The current estimate for TPC is $18.3M, with an average contingency value of 22%.

| WBS | Labor Estimate | ODC Estimate | Major Purchases | Contingency | TEC w/o Escalation | Escalation | TEC |
|---|---|---|---|---|---|---|---|
| 1.01 Research & Development | 64,537 | 265,161 | | 115,394 | 445,092 | 8,000 | 453,092 |
| 1.02 Polarized Neuron Beam Line & Shield | 209,143 | 162,100 | 1,274,687 | 216,193 | 1,862,123 | 241,000 | 2,103,123 |
| 1.03 Cryostats, Refrigerators | 774,679 | 808,840 | 2,149,000 | 727,543 | 4,460,062 | 362,000 | 4,822,062 |
| 1.04 3He Systems | 609,103 | 493,286 | 100,000 | 434,557 | 1,636,947 | 115,000 | 1,751,947 |
| 1.05 Magnets & Magnetic Shielding | 361,855 | 323,425 | 952,000 | 559,308 | 2,196,588 | 203,000 | 2,399,588 |
| 1.06 Central Detector System | 303,997 | 343,403 | 357,200 | 239,508 | 1,244,107 | 101,000 | 1,345,107 |
| 1.07 Electronics, Computers, Simulations | 104,907 | 97,090 | 209,000 | 44,177 | 455,174 | 51,000 | 506,174 |
| 1.08 Infrastructure | 243,039 | 239,530 | 140,440 | 194,499 | 817,507 | 102,000 | 919,507 |
| 1.09 Assembly & Commissioning | 751,028 | 114,218 | | 245,560 | 1,110,806 | 184,000 | 1,294,806 |
| 1.10 Project Management | 2,435,536 | | | 243,554 | 2,679,090 | 283,000 | 2,962,090 |
| **Grand Total** | **5,857,825** | **2,847,053** | **5,182,327** | **3,020,292** | **16,907,496** | **1,650,000** | **18,557,496** |

**Figure 6.** Breakdown of TPC by WBS

### 4.5.2 Life-Cycle Cost

The EDM Project life-cycle cost reflecting the TPC for design and construction, operation for the 5-year design life, and eventual decommissioning is estimated to be $21.25M. The breakout of this cost is the TPC of the project: $18.3M, an estimated operating cost of $0.45M/yr for a five-year total of $2.25M, and $0.5M D&D cost. The D&D cost is based on the recent decommissioning of another experiment of similar complexity at LANL.

### 4.5.3 Resource Planning

#### 4.5.3.1 Funding

The proposed annual budget authority for the initial baseline presented in this PPEP is summarized in Table 4.2, below. Conceptual-design efforts have continued and refined the proposed cost for individual WBS elements, and the schedule, the level of contingency, and the technical scope has not changed since CD-0 approval.

**Table 4.2 Budget Authority Profile**

| Fiscal Year | CD-1 Total Estimated Cost Estimated Budget Profile | Fiscal Year | CD-1 Total Estimated Cost Estimated Budget Profile |
|---|---|---|---|
| 2006 | $180,000 | 2010 | $5,000,000 |
| 2007 | $1,300,000 | 2011 | $3,000,000 |
| 2008 | $3,000,000 | 2012 | $870,000 |
| 2009 | $4,950,000 | | |

## 4.6 Quality Assurance

An EDM Project quality assurance (QA) program in accordance with DOE requirements will be implemented.

## 4.7 Project Monitoring and Assessment

The performance-measurement system will be part of the closed-loop project-controls system described in the *Project Controls Manual* document. The EDM Project Office will develop the performance-measurement and reporting system, maintain the system, generate project-wide reports, and distribute reports to appropriate personnel. The Subsystem Managers will generate performance data via the detail schedules, evaluate progress within Microsoft Project, generate reports, analyze variances, and implement corrective actions if needed. The essential ingredient in measuring performance will be up front definition of what is to be measured. In addition, reviews of the project status will be conducted annually by SC. Formal project reporting is in effect for the duration of the project, in accordance with the reporting requirements identified in DOE O 413.3 and this PPEP.

## 4.8 Project Contingency Management

Contingency is of two formal types: cost and schedule. Contingency is a predetermined amount of time or budget, based on relative risks, that is identified during early planning to provide for the uncertainties encountered in the execution phase of a project. Consistent with best practices, the EDM Project determines contingency from the “bottom-up” (at the activity level).

In developing the initial pre-CD-1 estimates for the project, Subsystem Managers use an iterative and sequential process to first identify assigned scope, then to estimate the time required to accomplish that scope and then estimate the resources required for scope accomplishment in the necessary timeframes. Numerous iterations were made throughout the planning cycle, so that scope, schedule and resources (cost) were considered holistically to ensure a complete, logically ordered, well-balanced, and realistic plan. This

planning used the judgment of subject matter experts, based on past related past experiences, as well as vendor information to derive the initial estimate.

Based on the Subsystem Manager assessment of technical, schedule, and cost risks at the individual activity level (within Work Packages), the EDM Project contingency process provides for the application of a weighted values that yield a composite contingency for the activity (this is expressed as a weighted percentage). The cost contingency for the activity is determined by applying the composite weighted contingency to the activity base cost. Schedule contingency is determined in the same manner, except that only the technical and schedule dimensions are considered in the development of the composite weighted contingency to be applied. The EDM Project contingency method accommodates that an activity may have schedule risk but considerable cost risk, or vice versa. For instance, fabrication of a part could be a standard process, but the need for composite materials to make that part may have significant cost uncertainty due to market fluctuations in special materials. A corresponding opposite example is that procurement of a fabricated part may be governed by a fixed-price contract, but have schedule uncertainty owing to an unforeseen backlog of work at the vendor.

The sum of individual activities cost and schedule contingency amounts are summarized through the WBS and for the EDM Project total contingency. The total cost contingency for the EDM Project is $3.02M, (22%) and the total EDM Project schedule contingency is 7 months (6% of 117 months from CD-0 to CD-4). Correspondingly, the planned EDM Project completion date (preliminary baseline) is represented as a range for purposes of CD-1. That range, with schedule contingency excluded and included, respectively, is 14-Jan-07 and 14-Jul-14. It is anticipated that further risk-mitigation actions by the EDM Collaboration and the DOE may reduce the latter date to an earlier period.

# 5. Project Change Control

An essential element of project-management systems is the control of changes to the project baselines and the implementation approach. The process for managing changes to the project are described in detail in the *Project Controls Manual* document. The change-control thresholds are identified in Table 5.1.

## Table 5-1. EDM Project Change-Control Thresholds

| Level | Cost | Schedule | Technical Scope |
|---|---|---|---|
| DOE-SAE (Deviation Threshold) | 25% increase to TEC (total estimated cost). | ≥6-month increase (cumulative in a project-level milestone date). | Changes to scope that affect mission-need requirement. |
| DOE-NP | Any increase in the TEC<br>**OR**<br>a cumulative allocation of >$500K contingency. | ≥3-month delay of a Level 1 milestone date. | Change of any WBS element that could adversely affect performance specifications. |
| DOE-LASO Federal Project Director Level 2 | A cumulative increase of >$200K in WBS Level 2<br>**OR**<br>a cumulative allocation of >$200K contingency. | >1-month delay of a Level 1 milestone date<br>**OR**<br>>3-month delay of a Level 2 milestone date. | Any deviation from technical deliverables that does not affect expected performance specifications. |
| EDM Contractor Project Manager Level 3 | Any increase of >$50K in the WBS Level 2 | >1-month delay of a Level 2 milestone date. | Technical design changes that do not impact technical deliverables. |

# 6. Project Risk Management

## 6.1 Introduction

The EDM Project uses a formal, systematic process for the management of risk. This process is compliant with the intent of DOE Order 413.3 and recognized best practices. Project risk will be managed according to a formal *EDM Project Risk Plan* document. This plan recognizes that risk is not a one-time event, but is a dynamic, ongoing reality throughout the life of the EDM Project.

Risk is defined as a possible event(s) that if they occur will likely have an adverse effect on the EDM Project. Risk is a consequence of an action. Nonetheless, it is the belief of the IPT that risk can be managed to a significant degree.

All major EDM Project participant organizations participate in the risk-management process, to include the DOE (HQ and Site Office), universities, and other organizations and participants comprising the EDM Collaboration. Within the project, the Subsystem Manager has a key role in identifying, assessing, and mitigating risks within their assigned WBS areas of responsibility.

Project risk management also has important relationship to other business processes, key amongst them being change management and contingency development. Throughout the Critical Decision process, the IPT and EDM CPM will seek to identify and suggest alternative project strategies that could reduce technical, schedule, or cost risk.

## 6.2 EDM Risk Profile

The overall *technical risk* of the project is considered more than moderate, but not high overall. The theoretical basis of the project is well established, but the technical challenge will be to design and configure a device of close tolerance that delivers the desired performance parameters. The EDM Project is a first-of-a-kind project, and the project includes a research element whose intent is to answer currently open physics- and science-related questions. The results of the research must be incorporated into the design in order to finalize the design effort. Technical integration is complicated by the need to configure the input of multiple participant organizations. However, these organizations also serve to reduce risk by ensuring the necessary physics and engineering expertise is available to the EDM Project. Technical risk is also mitigated by the use of many off-the-shelf catalogue equipment, materials, and hardware. For the principle reasons stated, the overall EDM Project risk is rated more than moderate, but not high overall.

*Schedule risk* is considered approaching moderate for the project overall. The schedule requires an exceptionally high degree of horizontal integration across participant organizations to ensure key predecessor and successor relationships are understood. Schedule risk is mitigated by several means, to include use of

- a professional scheduler,
- a standard schedule process,
- a common scheduling software,
- critical-path scheduling, and
- the use and identification of key milestones.

*Cost risk* is considered approaching moderate for the project overall. Contributors to cost risk are annual fiscal-year funding uncertainties, overhead rate relative stability, and materials cost in the marketplace. Cost risk is mitigated by the use of a standard resource/cost estimating process, resource-loaded schedules, and the use of activity-based costing principles. The overall project contingency is considered low for a first-of-a-kind project, but adequate with close management of the EDM Project.

Both schedule and cost plans as defined at the time of the CD-1 review are dependent on the funding schedule identified in the PPEP and CD-1 documentation. The project preliminary baseline will require adjustment if the funding profile is modified.

# 7. Environment, Safety, Health, and Security

## 7.1 National Environmental Policy Act

In compliance with the National Environmental Protection Act of 1969, as amended (NEPA) and its implementing regulations (10 CFR 1021 and 40 CFR 1500-1508), an environmental assessment (EA) will be prepared to evaluate the potential environmental consequences of constructing and operating EDM. If the EA determines that an Environmental Impact Statement (EIS) is required, that will be prepared. Otherwise, approval for a Finding of No Significant Impact (FONSI) will be sought.

## 7.2 Plant Safety

A primary objective of the EDM Project is to design and construct an experimental apparatus that meets mission goals and that also protects the environment and the safety of workers and the general public. An integrated safety management system (ISMS) approach will be applied to the EDM Project. In addition, the EDM Federal Project Director is responsible for establishing and approving the safety basis and operations in accordance with DOE Orders.

## 7.3 Waste Minimization & Pollution Prevention

An objective of the EDM Project is to minimize the amount of waste generated during the full equipment life cycle (construction, operation, and decommissioning). This will be achieved through design choices that reduce the kinds and amounts of waste, by recycling materials to the extent feasible, and proper treatment or pretreatment of waste streams.

## 7.4 Construction/Industrial Safety

Safety of the workforce, safe transport and installation of components, and safe checkout and startup of the equipment are prime EDM Project goals. Project participants will enforce safety requirements and rules. To the extent possible, SNS safety standards will be applied to equipment-construction activities.

# 8. Transition to Operations

Once the EDM Project is complete, the responsibility for completion of the scientific program will be transferred to the scientific spokespersons and the Executive Committee of the EDM Collaboration. The maintenance of the apparatus will be managed by the physics department of ORNL for a budget of $450K/yr. This amount should cover expendables, equipment replacement when necessary, operations under the supervision of an ORNL scientist with the appropriate technical background, and an ORNL technician.

## 8.1 Equipment Startup

Checkout, test, acceptance, and pre-operations of equipment components will be addressed by appropriate planning for all aspects of bringing the individual components on line, to support integrated operation of the complete system, to demonstrate and address the operating procedures and maintenance requirements of the equipment, and to provide the necessary technical personnel and operator training and qualification.

## 8.2 Lessons Learned

Lessons-learned discussions will be initiated after CD decisions are rendered by the DOE to ensure full understanding of the EDM Project feedback provided by DOE.

Near the conclusion of the EDM Project, lessons learned of "*what went right*" and "*what went wrong*," as well as insights into what might have been done better, will be assessed and documented.