Preliminary Hazard Identification and Analysis Plan

for the

Neutron Electric Dipole Moment Project (nEDM)

Project MIE #71RE

at

Los Alamos National Laboratory
Los Alamos, New Mexico
managed by
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List of Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
AHJ	Authority Having Jurisdiction
ASME	American Society of Mechanical Engineers
CW	continuous wave
DID	defense in depth
DOE	Department of Energy
dTPB	deuterated tetraphenyl butadiene
FM	factory mutual
FNPB	Fundamental Neutron Physics Beamline
FSAD	Final Safety Assessment Document for Neutron Facilities (SNS Document 102030102-ES0016)
ISMS	integrated safety management system
JHA	job hazard analysis
LANL	Los Alamos National Laboratory
LO/TO	lockout/tagout
MSDS	material safety data sheet
NEC	National Electric Code
nEDM	electric dipole moment of the neutron
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
ODH	oxygen deficiency hazard
OPM	operations procedures manual
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PPE	personnel protective equipment
RF	radio frequency
SBMS	standards-based management system
NFDD	SNS Neutron Facilities Development Division
NSSD	SNS Neutron Scattering Science Division
SNM	special nuclear material
SNS	Spallation Neutron Source (ORNL)
TLV	threshold limit value
UCN	ultracold neutrons
UL	Underwriters Laboratories

1 Introduction

This document describes the preliminary hazard identification and analysis performed for the neutron Electric Dipole Moment (nEDM) experiment. nEDM will be constructed by collaborating institutions and executed at the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source (SNS), located at Oak Ridge National Laboratory (ORNL). The project office for the nEDM experiment is located at Los Alamos National Laboratory (LANL).

The SNS is an accelerator-based neutron source in Oak Ridge, Tennessee, built by the U.S. Department of Energy (DOE). The SNS will provide the most intense pulsed neutron beams in the world for scientific research and industrial development. At a total cost of $1.4 billion, SNS construction was recently (2006) completed. The SNS is a national user facility, open to scientists from universities, industries, and federal laboratories. It is anticipated that the facility, when fully operational, will be used by 1,000–2,000 scientists each year. The SNS target station has the capacity to host 24 beamlines (instruments).

The FNPB is located on SNS beamline #13, which views one of the cold, coupled, unpoisoned moderators (the moderator type with the highest fluence). The FNPB has two separate experimental areas. One experimental area, inside the main SNS target building is suitable for experiments (such as precision measurements of neutron β-decay correlations and parity-violation) that can make use of the full neutron energy spectrum. A second experimental area will be located in a building outside the main target building (where it can be isolated from vibrations and radioactive backgrounds) and is suitable for experiments that study ultracold neutrons (UCNs) generated by stopping neutrons of a particular energy (or wavelength, λ ~0.89 nm) inside liquid helium-4. The nEDM experiment will be assembled and operated inside this external building. Figure 1 shows a schematic drawing of the nEDM apparatus.

The nEDM apparatus consists of a number of separate subsystems (the cryogenic vessel, the magnetic coils and shielding, the central detector system, the helium-3 system, and neutronics [neutron guide and shielding]). These subsystems will be developed and tested at collaborating institutions. The magnetic coils, central detector system, and the helium-3 system will be assembled into the cryogenic vessel at the SNS FNPB, integrated with the neutronics and the magnetic shielding, commissioned, and operated.

In this document, we define the hazards that will be encountered at the SNS site during assembly, commissioning, and operation of the nEDM apparatus. We also discuss the corresponding engineering and administrative controls to mitigate these hazards. After the nEDM apparatus is turned over to the SNS facility, the SNS work control policy as discussed in Section 4.1.2.1 of SNS Document 102030102-ES0016, *Spallation Neutron Source Final Safety Assessment Document for Neutron Facilities* (FSAD) applies. Job Hazard Analysis (JHA) is done, as needed, to identify the standard industrial hazards and to match them to control measures applied by workers in the field. The focus of this hazard analysis process is on hazards unique to the nEDM experiment. Standard industrial hazards are not addressed because they are controlled through existing ORNL and SNS policies and procedures, utilizing existing codes, standards, and regulations.

Hazards that may be encountered at other collaborating institutions (during development and testing of various subsystems before the final assembly at the SNS site) are subsets of the hazards listed here. The general policy of the nEDM collaboration is that safety will be integrated into all aspects of work performed in accordance with DOE expectations and the safety policies of the institution where the work is being done. Hazard Analysis results, mitigation techniques, and associated procedures will be communicated to collaborators at all institutions where related work will be carried out. The LANL project office will examine operations at the institutions to verify that they are consistent with the LANL Integrated Work Management Program, as documented in LANL IMP-300. It should be noted that the other institutions where work will be performed are universities governed by Occupational Safety and Health Administration (OSHA) regulations and other DOE national labs. Web links to some of the Environmental, Safety, and Health homepages are listed here:

University of Illinois, Urbana-Champaign	http://phantom.ehs.uiuc.edu/
University of California, Berkeley	http://ehs.berkeley.edu
North Carolina State University	http://www.ncsu.edu/ehs/healthsafety_man.htm
Arizona State University	http://www.asu.edu/uagc/EHS/
California Institute of Technology	http://www.safety.caltech.edu/home.htm
Massachusetts Institute of Technology	http://informit.mit.edu/ehs-ms/
Duke University	http://www.safety.duke.edu/

All work in the SNS FNPB will be performed within ORNL, SNS and Physics Division Integrated Safety Management System (ISMS) and Standards Based Management System (SBMS) requirements and safe work practices. By following applicable ORNL, SNS, and Physics Division procedures, as well as applicable codes and standards, hazards will be eliminated or mitigated to acceptable levels to ensure a safe work environment.

The SNS FSAD is the safety document for beamlines at the SNS. A number of nEDM components, including reflective neutron guides, beam benders, secondary shutters, beam monitors, neutron beamline vacuum systems, magnets, neutron beamline utilities, and neutron beamline shielding are similar in form and function to other beamlines at the SNS. These items are described in Section 3.3.13 of the FSAD. The potential hazards posed by elements common to all or some of the beamlines are addressed in Section 7 of the FSAD. The FSAD also addresses many standard industrial hazards, such as flammable materials and chemical storage, crane and forklift usage, etc.

Because the nEDM experiment will ultimately reside within the SNS facility, it will be subject to all applicable SNS quality-assurance and safety requirements for component design and certification and hazard-mitigation techniques. To ensure compliance with SNS requirements, we will conduct comprehensive design reviews, at appropriate stages of the design, with participation by representatives of the SNS Neutron Scattering Science Division (NSSD) and Neutron Faciliteis Development Division (NFDD). Safety professionals from collaborating institutions will be included in the design reviews to ensure that component design and certification and hazard-mitigation techniques satisfy requirements at all institutions where the corresponding work will be performed.

The nEDM experiment will be subject to all requirements for experiments operating at the SNS, including a comprehensive Safety Readiness Review before instrument commissioning as described in Section 3.4.6 of the SNS FSAD.

Environmental consequences of SNS instruments are addressed in the SNS Environmental Impact Statement (DOE/EIS-0247). No additional National Environmental Policy Act (NEPA) documentation is required. As a result, the hazard analysis contained in this document does not address these issues.

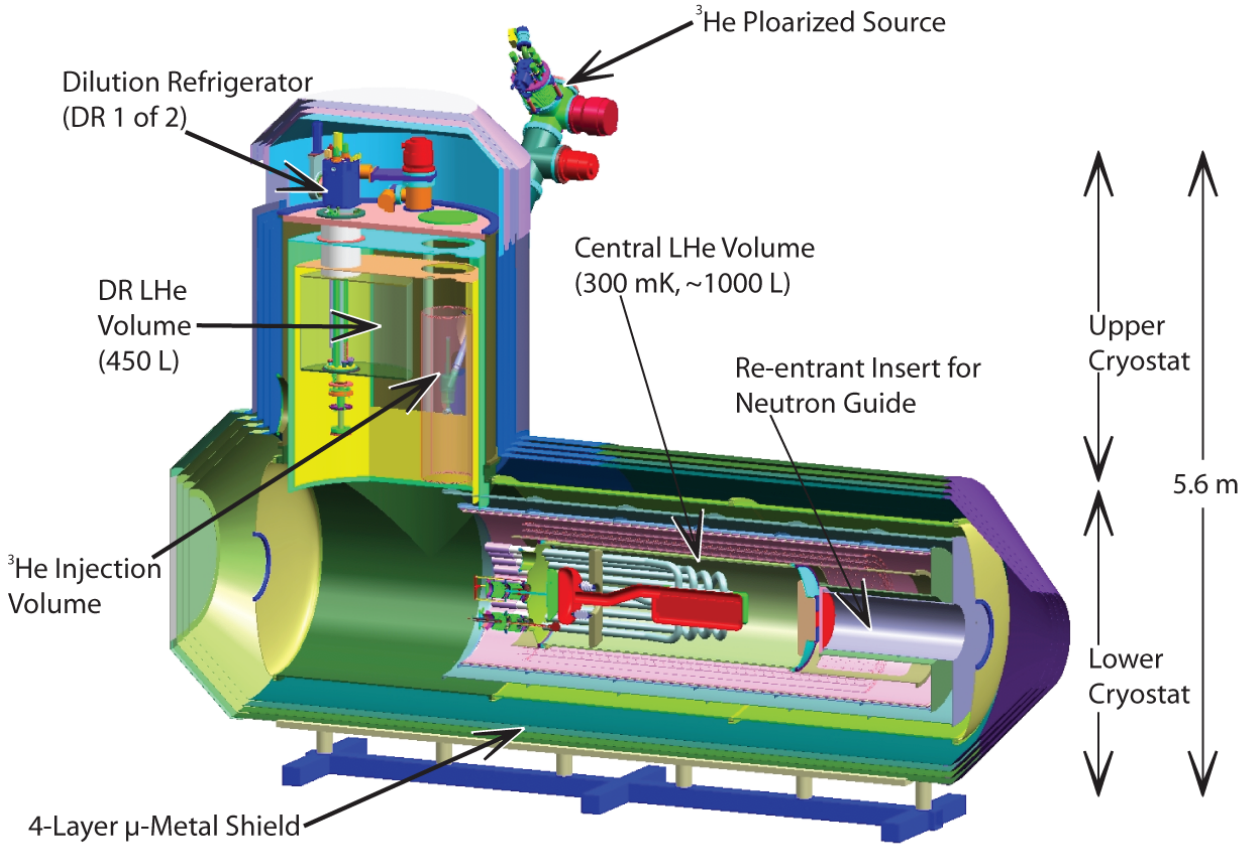

Figure 1. Schematic diagram of the nEDM apparatus.

2 Hazard Analysis Methodology

Hazard analysis includes the following steps: (1) hazard identification and screening; (2) assessment of the potential consequences of unmitigated risk; (3) identification of relevant and effective mitigation/preventive measures; and (4) assessment of mitigated risk. Hazard analysis is a process whereby it is possible to understand the risk and make informed risk mitigation or acceptance decisions.

It is desirable to identify and apply safety measures that make the risks associated with the SNS Accelerator Facility, including the nEDM experiment, fall into the “extremely low” category (see figure 2 below).

The steps in the hazard analysis process and general decision criteria are shown below. Hazard identification produces a comprehensive list of the hazards present in a process or facility, and the screening phase moves all hazards below a threshold of concern or ensures that they are covered by recognized industrial codes and standards. The hazards that are “screened out” do not need to be studied in a hazard analysis because their risks are already well understood and acceptable. For each hazard retained for hazard analysis, the unmitigated risk is first evaluated in terms of frequency and consequence. This places it on the risk matrix (see figure 2). The following assumptions govern the determinations of unmitigated risk:

- The unmitigated risk does not include safety or control systems or administrative controls.
- Assigned frequencies (labeled “Probability Level” on figure 2) are based on engineering judgment. For the unmitigated evaluation, the frequency is that of the unmitigated initiating event. See Appendix B for examples.
- Assigned consequence can be qualitative but must be conservative.
- If the unmitigated risk is extremely low, the process can stop at this point. Otherwise, proceed to the evaluation of mitigated risk.

At this point, the risk is reevaluated considering the mitigating factors in place that would either reduce the consequence or make the challenge less frequent. This should move the location on the risk matrix based on assumed conditional probabilities of failure for the mitigating systems (see Appendix B for discussion on assignment of conditional probabilities to failure of mitigating systems or actions).

- At this point, the mitigated risk should be either low or extremely low. For low risk, the evaluation should be reviewed to determine if there are preventive or mitigating features that could be credited to bring the risk to extremely low. The risk of serious consequences should be made extremely low if that is reasonably achievable.
- The last step is to determine whether it is necessary to designate any equipment as Safety Significant using the approach discussed below.

The purpose of Safety Significant designation is to highlight a minimum number of equipment items and/or administrative controls needed to ensure safety. The set should be minimal so that the Safety Significant equipment can be designed and appropriately treated and considered for incorporation in the requisite procedures and/or QA documents.

If the unmitigated consequence is conservatively evaluated to be fatal for a hazard that is not a standard industrial hazard, then a Safety Significant designation should in general, be made. Equipment is selected in favor of administrative controls if at all practical. If there are several mitigating or preventive features, and any single one can control the hazard adequately it may not be necessary to designate a Safety Significant feature.

The term Safety Significant, as used in this document follows the definition found in the Occurrence Reporting and Processing of Operations Information. However, its usage here is in relation to personnel safety and has nothing to do with nuclear safety or protection of the public (civilian accelerators do not pose a threat to members of the public).

Consequence Level				
High	*Low Risk-Acceptable*	*Medium Risk-Unacceptable*	*High Risk-Unacceptable*	*High Risk-Unacceptable*
Medium	*Extremely Low-**Desirable***	*Low Risk-Acceptable*	*Medium Risk-Unacceptable*	*High Risk-Unacceptable*
Low	*Extremely Low-**Desirable***	*Extremely Low-**Desirable***	*Low Risk-Acceptable*	*Medium Risk-Unacceptable*
Extremely Low	*Extremely Low-**Desirable***	*Extremely Low-**Desirable***	*Extremely Low-**Desirable***	*Low Risk-Acceptable*
	Extremely Unlikely ($<10^{-4}$/a)	**Unlikely (between 10^{-4}/a and 10^{-2}/a**	**Anticipated-Medium (between 10^{-2}/a and 10^{-1}/a)**	**Anticipated-High (above 10^{-1}/a)**

Probability Level →

Definition of Consequence Levels	
Level	**Definition**
Extremely Low	*Will not result in a significant injury or occupational illness or provide a significant impact on the environment.*
Low	*Minor on-site with negligible off-site impact. May cause minor injury or minor occupational illness or minor impact on the environment.*
Medium	*Major impact on-site or off-site. May cause deaths, severe injuries, or severe occupational illness to personnel or major damage to a facility or operation or minor impact on the environment. Capable of returning to operation.*
High	*Serious impact on-site or off-site. May cause deaths or loss of the facility operation. Possible significant impact on the environment.*

Figure 2. Hazard Risk Analysis Matrix.

3 Hazard Identification and Analysis

To initiate the hazard screening process for nEDM, we used the screening tables (Tables A-1–A-5) shown in Appendix A. Many of the identified hazards are addressed within the existing SNS FSAD. However, a number of identified hazards require some more discussion and analysis. Subsections 3.1 through 3.14 describe these hazards, including radiation (ionizing and non-ionizing), magnetic field, laser, fire, oxygen deficiency, vacuum and pressure, cryogenic, elevated work, chemical, hoisting and rigging, confined space, electrical and mechanical hazards.

Hazards analysis results are summarized in Table 1. Tables 2 through 8 summarize the risk evaluation for those hazards which required some degree of mitigation to achieve an acceptable risk level.

3.1 Radiation and Radioactive Materials Hazards

Tests of the nEDM experiment with radioactive sources (α and β) are anticipated.

Accessing the nEDM experimental apparatus with the primary and secondary shutters open is a potential radiation hazard. This risk must be mitigated with engineering controls such as interlocks. Exposure to the neutron beam may activate components of the beamline and the experimental apparatus, which could also lead to contamination hazards. Note: The nEDM beamline only transmits a narrow energy slice of neutrons and never sees the moderator or the prompt neutron or γ-flash because the input neutrons pass through a double monochromator. As such, radiation hazards and activation of components are expected to be minimal.

nEDM radiation hazards are subject to SNS and ORNL policies and procedures. Source usage is subject to ORNL and SNS policies and procedures. Radiation limits for the Target Building and external instrument buildings have been set in accordance with 10 CFR 835 and the SNS Shielding Policy, including a shielding requirement to limit radiation levels to less than 0.25 mrem/hr in unrestricted work areas and a design goal to limit radiation levels to less than 2 mrem/hr in areas with restricted access. The SNS Operations Procedures Manual (OPM) includes the administrative procedures that implement these policies.

The probability of occurrence for ionizing radiation exposure hazards is determined to be medium, and the unmitigated consequences are determined to be low, thus making the resultant risk low (acceptable). With application of SNS procedures and controls for radiation shielding and restricted access areas, the resultant mitigated risk is extremely low.

3.2 Non-ionizing Radiation Hazards

The nEDM experiment incorporates two types of radio-frequency (RF) generators:

1. RF spin flippers (one for each of the two measurement cells) will be used to alternate the neutron spin orientation entering the cells. It is anticipated that these will operate at 20–40 kHz, with a maximum total power of a few hundred Watts.
2. “Dressing coils” will be used to equalize the neutron and helium-3 co-magnetometer precession frequencies. These are anticipated to operate at 3 kHz with a power of only a few Watts.

Occupational exposures will remain below the Threshold Limit Values (TLV) in the latest ACGIH (American Conference of Governmental Industrial Hygienists) TLV booklet, as per ORNL SBMS policy. Detailed analysis will be required to determine required warning postings and whether access will be restricted during operation.

The probability of occurrence for non-ionizing radiation exposure hazards is determined to be medium, and the unmitigated consequences are determined to be medium thus making the resultant risk medium (unacceptable). The primary concern with non-ionizing radiation is the exposure hazard to pacemaker wearers. With application of ORNL SBMS procedures and controls for non-ionizing radiation (including safeguards for pacemaker wearers), the resultant mitigated risk is extremely low (See Table 2).

3.3 Magnetic Field Hazards

Both static and time-varying magnetic fields will be used in the nEDM experiment. Static fields to guide the neutron spin will be in the 5–10 Gauss range along the neutron beamline. Static guide fields inside the measurement cell will be

smaller (<1 Gauss) and extremely well-shielded. Time-varying fields inside the apparatus, from the RF Spin Flippers and "Dressing coils" described in Section 3.2, are much smaller.

The SNS policy on magnetic fields, described in Section 7.5 of the FSAD, states that regions with fields greater than or equal to 5 Gauss must be plainly marked and posted with signs stating "No Pacemakers or Other Medical Electronic Devices." Furthermore, personnel involved in operating, maintaining, and testing magnets will be trained in the associated hazards.

The probability of occurrence for magnetic field exposure hazards is determined to be medium, and the unmitigated consequences are determined to be medium, thus making the resultant risk medium (unacceptable). The primary concern with magnetic fields is the exposure hazard to pacemaker wearers. With application of ORNL and SNS procedures and controls for magnetic fields (including safeguards for pacemaker wearers), the resultant mitigated risk is extremely low (See Table 3).

3.4 Laser Hazards

The nEDM experiment will incorporate a laser to allow measurement of the voltage applied to the measurement cell through the Kerr effect (rotation of laser polarization is dependent on the material and the field). The laser is likely to be a CW (continuous-wave) frequency-doubled Nd:YAG laser, 532 nm, 10 mW. This laser is classified as Class 3B by ORNL SBMS.

ORNL SBMS specifies requirements for working with lasers, which includes but is not limited to, training, administrative and engineering controls, a standard operating procedure, and medical surveillance (eye exam).

The probability of occurrence for laser exposure hazards is determined to be medium, and the unmitigated consequences are determined to be medium, thus making the resultant risk medium (unacceptable). With application of ORNL and SNS procedures and controls for laser hazards (in accordance with ANSI Z136.1-2000), the resultant mitigated risk is extremely low (See Table 4).

3.5 Fire Hazards

The only flammable materials in the nEDM experiment are electrical cables (which will be subject to review by the SNS Electrical Safety Review Committee), the small amount of polystyrene in the measurement cell (which will be encased in the metallic cryostat vessel, and which will be in a pool of liquid helium during operation), and (possibly) hydrocarbon-based shielding components.

SNS is following National Fire Protection Association (NFPA) 101 "The Life Safety Code" for matters relating to personnel fire protection. SNS OPM Procedure Section 2.J-2 "Fire Safety" and the FSAD Sections 3.3.10.3 and 7.4 deal with fire-protection systems. In addition, SNS OPM Procedure 7.T-200.5, "Target Facility Combustible Control Program" contains requirements that must be met (e.g., 100 lbs of hydrocarbon shielding requires additional review).

The probability of occurrence for fire hazards is determined to be unlikely, and the unmitigated consequences are determined to be low, thus making the resultant risk extremely low (acceptable). Application of ORNL and SNS fire protection procedures further mitigates the risk.

3.6 Oxygen Deficiency Hazards

The nEDM experiment contains roughly 1500 L of liquid helium. If this became gas in the nEDM building, it would displace sufficient amounts of air to create an asphyxiation hazard. A cryostat blow-off would be readily detectable by someone in the room. Of primary concern would be entry into the building after such an event has occurred and for which the warning signs (vapor cloud, venting sounds) are no longer present. Personnel involved in complex cryogenic operations are required to receive adequate cryogenic safety training and to follow Safety for Cryogenic Operations at SNS (See Appendix D of the SNS FSAD).

SBMS policies and procedures, supplemented by SNS policies ensure that any needed mitigation features (e.g., safety interlocks or alarms) are employed. Appropriate protection, training, and procedures are required to ensure that the hazard is appropriately mitigated in all phases of design and operation. Cryogenic-system design and operations will be subject to review by the SNS Cryogenic Safety Review Committee.

The probability of occurrence for oxygen deficiency hazards is high. The consequence of an unmitigated oxygen deficiency event is medium, making the unmitigated risk high (unacceptable). Engineered controls, such as pressure release valves and automated interlocks, plus applicable ORNL and SNS procedures, standards, and training, and experiment review as required, combine to provide abundant defense in depth (DID) to make the mitigated risk of oxygen deficiency hazards extremely low (see Table 5).

3.7 Vacuum and Pressure Hazards

The neutron guide (like many in the SNS) and the nEDM experimental apparatus will be operated under vacuum. Implosion of vacuum components could oppose a potential hazard from flying objects. Vacuum systems at the SNS must be designed to meet, withstand, or eliminate the full range of stresses encountered in vacuum service and are subject to the general instrument safety-review process. Vacuum components, except for neutron windows, are constructed of heavy-walled material per the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, to minimize the threat of implosion when evacuated. Vacuum window lifetime is evaluated conservatively so that windows are changed before they fail accidentally in service. Neutron windows and feedthroughs are protected from casual impacts or striking objects.

When the nEDM experimental apparatus is not in operation the 1500 L of liquid helium will be in a storage tank outside the nEDM building. This pressure vessel will be subject to ORNL SBMS policies and procedures which require ASME certification and stamp or vendor certification of maximum allowable working pressure and routine quality inspections.

Loss of insulating vacuum in the experimental apparatus would heat the liquid helium rapidly, possibly resulting in a sudden release of high-pressure gasses. The apparatus will be engineered with redundant and tested pressure-release valves. A testing program in accordance with SNS-QA-P081 will be developed to periodically evaluate the performance of the valves. The principal release path will be to the storage tank mentioned above. In the advent of blockage of this path, there will be a higher-pressure release path into atmosphere. In the case of a sudden release that exceeds the flow capacity of the standard lines, a large emergency-vent valve and line will be installed to exhaust the helium outside the building.

During the transfer of cryogens, the possibility of trapping water or air in lines can lead to blocked passages and isolated volumes. These volumes can become overpressured. The transfer of cryogens can be accomplished without trapping water or air by the use of proper techniques. All workers who transfer cryogens will be required to have job-specific training to ensure they understand the hazards of frozen gases and how to prevent such occurrences. In addition, an analysis will be done to identify all spaces in the system that can become isolated, and pressure-relief valves will be installed for these volumes.

The probability of occurrence for vacuum and pressure hazards is determined to be medium. The unmitigated consequence is determined to be medium, yielding medium (unacceptable) unmitigated risk. The design criteria for vacuum vessels, including use of shields for neutron windows, lockout/tagout (LO/TO) of vacuum source (and nitrogen or other inert purge gas lines) when close personnel access is required, and possible use of automatic interlocks, combined with the beam line and experiment review processes combine to make the mitigated risk extremely low (See Table 6).

3.8 Cryogenic Hazards

Transfer of liquid nitrogen and helium from various size dewars is considered to be standard industrial practice. Appropriate personnel protective equipment is required when handling cryogenic liquids. Personnel involved in complex cryogenic operations are required to receive adequate cryogenic safety training and to follow Safety for Cryogenic Operations at SNS (See Appendix D of the SNS FSAD). Instrument components designed for cryogenic use are reviewed by the SNS Cryogenic Safety Review Committee.

The probability of occurrence for cryogenic hazard initiator events is medium. The consequence of an unmitigated cryogenic accident is low, making the unmitigated risk low (acceptable). With application of appropriate SNS procedures, standards, and training for handling cryogenic fluids, and experiment review as required, the mitigated risk of cryogenic hazards is extremely low.

3.9 Elevated Work Hazards

The nEDM apparatus rises 6 m above the floor of the nEDM building. OSHA-compliant ladders and platforms will be incorporated into the design. Under unusual circumstances, it may be necessary to work outside the platform structure. In these cases an SBMS or OSHA-compliant fall-protection plan will be utilized. In all cases, appropriate training will be required.

The probability of occurrence for fall hazards is medium. The consequence of an unmitigated fall accident is medium, making the unmitigated risk medium (unacceptable). With application of appropriate SBMS and OSHA-compliant fall protection, the mitigated risk of fall hazards is extremely low (see Table 7).

3.10 Chemical Hazards

Most chemical hazards associated with the nEDM experiment will be common to many experiments at the SNS (small quantities of acetone and/or alcohol for cleaning surfaces, lead shielding, solder, pump-oil waste, etc.).

In addition to these standard chemicals, nEDM will likely use commercially available, thin beryllium foils in the neutron entrance window. Any work with beryllium will be independently reviewed in accordance with ORNL, SNS, and Physics Division requirements. Beryllium activities will be conducted under a project-specific beryllium protection plan.

Lithium-6 may be incorporated into shielding element. Although not hazardous, lithium-6 is Special Nuclear Material (SNM) and any use of SNM will be in accordance with the Security Plan for the SNS Material Balance Area.

Also, during construction of the measurement cells a deuterated wavelength shifter, tetraphenyl butadiene (dTPB) will be applied to the surface of the acrylic cells. This chemical will most likely be purchased commercially. In the unlikely event that the collaboration synthesizes the dTPB, procedures will be developed to do so safely. The dTPB is dissolved in deuterated styrene using deuterated toluene. This mixture is applied to certain surfaces within the apparatus and allowed to evaporate to a uniform coating on the surface.

Chemicals will be stored in appropriate chemical-storage and flammable-materials cabinets. Waste-accumulation areas will be established, as needed, per ORNL and SNS standards and/or procedures, and responsible operations personnel will receive appropriate training. Access to Material Safety Data Sheets (MSDSs) is required for all chemicals in use. Personnel handling these materials are required to receive adequate training in specific chemical-handling procedures and proper use of MSDSs. Chemical use is subject to ORNL and SNS policies and procedures and is subject to the experiment safety-review process, as described in Section 7.1 of the FSAD.

The probability of occurrence for chemical accidents is anticipated to be medium, and the unmitigated consequences are low, making resultant risk low (acceptable). OSHA-compliant (e.g., 29 CFR 1910.1200)4 HAZCOM standards and/or directives, training, and beam line and experiment review processes provide levels of mitigation that result in an extremely low mitigated risk.

3.11 Hoisting and Rigging Hazards

Assembly of the nEDM experiment apparatus at the SNS will require use of forklifts, an overhead crane, and specialized lifting equipment.

Lifting operations at the SNS are conducted in accordance with the SNS Hoisting and Rigging Program (SNS 104070400-PR0005-R0). The SNS Hoisting and Rigging Program provides a structured approach for hoisting and rigging activities, establishes operator qualifications and training requirements, and ensures equipment is maintained in proper operating conditions.

The probability of occurrence for hoisting and rigging accidents is anticipated to be medium, and the unmitigated consequences are low, making resultant risk low (acceptable). The SNS Hoisting and Rigging Program requirements provide levels of mitigation that result in an extremely low mitigated risk.

3.12 Confined-Space Hazards

The nEDM cryogenic vessel and the liquid-helium storage tank outside the nEDM building are confined spaces. They are normally filled with liquid helium, but personnel may enter to perform work during assembly, commissioning, and maintenance. This situation is common to many SNS instruments.

Initial access to these confined spaces will be conducted under a confined space permit. Once safe oxygen levels have been verified per OSHA Standard 29 CFR 1910.146, and all other potential hazards have been eliminated, these spaces may be downgraded to a confined space not requiring a permit for access. Workers who enter confined spaces will be trained and qualified in accordance with ORNL and SNS policies and procedures.

The probability of an accident in a confined space is unlikely, and the unmitigated consequences are medium, making resultant risk low (acceptable). The ORNL Confined Space Program requirements provide levels of mitigation that result in an extremely low mitigated risk.

3.13 Electrical Hazards

In addition to the common electrical hazards associated with many SNS experiments, the nEDM experiment employs large vacuum pumps and systems that use 480 V 3-phase power. The hazards from this type of power are significantly worse than with 120 or 240 V power. There is also high voltage (~500 kV) with very low current ($<10^{-9}$ A) applied across the measurement cell via a capacitor of ~100 pF, resulting in a total stored energy of 5–10 J.

Experimental devices at the SNS are required to meet the intent of the National Electric Code (NEC). Therefore NEC rules (e.g., fusing, connector types and cable types) are followed for instruments where reasonably achievable. Any deviation from NEC rules requires a written request substantiating why an exception is required and subsequent Authority Having Jurisdiction (AHJ) approval. The SNS FSAD Section 5.3.4 explains the approach followed to minimize the possibility for instrument systems to become an ignition source for fire. Installation of equipment and electrical utility routing will conform to applicable codes and requirements. Instrument equipment must be Underwriters Laboratories Inc. (UL) listed and/or factory mutual (FM) approved or requires approval by the SNS Electrical Safety Review Committee.

All personnel performing service on equipment are required to receive training in, and adhere to, SNS ORNL lockout/tagout (LO/TO) policies. Work on energized equipment may be required. Only specifically qualified personnel will perform such work. Such individuals will be capable of working safely on energized circuits and will be familiar with proper use of precautionary techniques, personnel protective equipment (PPE), insulating and shielding materials, and insulated tools. Any work on energized circuits must be in accordance with SNS Procedure 104070400-PR0008-R01, Electrical Safety, “Working on or Near” or “Working Hot”.

The probability of occurrence for electrical accidents is medium, and the unmitigated consequences are medium, making resultant risk medium (unacceptable). These electrical hazards are considered to be standard industrial hazards well controlled by ORNL and SNS policies, procedures and training, resulting in an extremely low mitigated risk.

3.14 Mechanical Hazards

As with most SNS experiments, the nEDM experiment will contain rotating machinery including pumps, blowers, motors (secondary shutter), etc. Proper guarding will be incorporated in the design and procedures require equipment to be locked out before the safety guards are removed for servicing of the equipment.

The probability of occurrence for mechanical accidents is medium, and the unmitigated consequences are low, making resultant risk low (acceptable). These mechanical hazards are considered to be standard industrial hazards well controlled by ORNL and SNS policies, procedures and training, resulting in an extremely low mitigated risk.

Table 1. Summary of nEDM Hazards Analysis.

Hazard Type	Presence	Unmitigated Hazard Level	Mitigation	Mitigated Hazard Level
Prompt Radiation	Worker enters instrument enclosure with shutter open. Anticipated exposure potential is considered to be minimal.	Low	10 CFR 835, ORNL SBMS Rad Protection Procedures, SNS Shielding Policy; training; interlocks.	Extremely Low
Activation	Exposure from beamline components upon decommissioning.	Low	10 CFR 835, ORNL SBMS Rad Protection Procedures	Extremely Low
Radio-frequency Field	Near experimental apparatus. Fields not a risk except for pacemaker wearers.	Medium	ORNL SBMS Procedure, "Working With Non-Ionizing Radiation"	Extremely Low
Magnetic Field	Near neutron guide. Fields not a risk except for pacemaker wearers.	Medium	ORNL SBMS Procedure, "Working With Non-Ionizing Radiation"	Extremely Low
Laser	Not generally accessible Hazard only during alignment/system development	Medium	ANSI Z136.1-2000	Extremely Low
Fire	Routine; minor amounts of combustible shielding materials.	Extremely Low	SNS Operations Procedures 2.J-2, "Fire Safety" and 7.T-200.5, "Target Facility Combustible Control Program"; nEDM building fire protection system	Extremely Low
Oxygen Deficiency	FNPB experimental building in case of cryogenic failure in experimental apparatus.	High	ASME Boiler and Pressure Vessel Code, Section VIII and ASME Codes B31.1 through B31.7 (for piping systems) ; nEDM building designed to passively vent cryogens; training and use of monitoring devices.	Extremely Low
Vacuum and Pressure	Neutron guide, external helium storage vessel, experimental apparatus under cryogenic failure conditions.	Medium	ASME Boiler and Pressure Vessel Code, Section VIII	Extremely Low

Hazard Type	Presence	Unmitigated Hazard Level	Mitigation	Mitigated Hazard Level
Cryogenic	Possible during operations, construction.	Low	SNS Safety Training for Cryogenic Operations	Extremely Low
Elevated Work	Possible during operations, construction while accessing elevated (6m) portions of the experimental apparatus.	Medium	ORNL SBMS Procedure, "Walking/Working Surfaces and Fall Protection"	Extremely Low
Chemical	Possible during construction.	Low	ORNL SBMS Subject Area "Chemical Safety"	Extremely Low
Hoisting and Rigging	Equipment lifts.	Low	SNS Hoisting & Rigging Program SNS 104070400-PR0005-R0	Extremely Low
Confined Spaces	Experimental apparatus, external Helium storage tank. Not normally accessible.	Low	ORNL SBMS Subject Area "Confined Space"	Extremely Low
Electrical	Common industrial hazard (<240VAC). Some equipment at 480 VAC. High Voltage system (500kV; 5-10J stored energy).	Medium	ORNL SBMS Subject Areas "Electrical Work" and "Lockout/Tagout"	Extremely Low
Mechanical	Pumps, blowers, power tools, etc.	Low	ORNL SBMS Procedure "Machine Guarding"	Extremely Low

Table 2. Qualitative Risk for Radiofrequency Field Hazards in nEDM.

Facility Name: FNPB External Building Number: nEDM-1
System: nEDM
Subsystem: Central Detector System
Hazard: Radiofrequency Fields

Event	Pacemaker operation disrupted.
Possible Consequences, Hazards	A person with a pacemaker unknowingly comes too close to the RF fields, leading to death or permanent disability. Without a pacemaker the risk is extremely low.
Potential Initiators	Poor signage, violation of established barriers.

Risk Assessment Prior to Mitigation:

Note: Refer to figure 2 for an explanation of consequence, frequency, and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	() High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	(X) Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	**( ) High**	**(X) Medium**	**( ) Low**	**( ) Extremely Low**

Hazard Mitigation	In accordance with ORNL SBMS Procedure, “Working With Non-Ionizing Radiation”; controls include surveys of RF, hazard warning postings, access restrictions for pacemaker wearers.

Risk Assessment Following Mitigation:

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	( ) Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	**( ) High**	**( ) Medium**	**() Low**	**(X) Extremely Low**

Is the mitigated hazard adequately controlled by existing laboratory policies? Y/N Yes

If no, roll up into SNS Accelerator Safety Envelope (ASE).

Table 3. Qualitative Risk for Magnetic Field Hazards in nEDM.

Facility Name: FNPB External Building Number: nEDM-2
System: nEDM
Subsystem: Neutronics
Hazard: Magnetic Fields

Event	Pacemaker operation disrupted.
Possible Consequences, Hazards	A person with a pacemaker unknowingly comes too close to the magnetic fields, leading to death or permanent disability. Without a pacemaker the risk is extremely low.
Potential Initiators	Poor signage, violation of established barriers.

Risk Assessment Prior to Mitigation:

Note: Refer to figure 2 for an explanation of consequence, frequency, and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	(X) Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	**( ) High**	**(X) Medium**	**( ) Low**	**( ) Extremely Low**

Hazard Mitigation	In accordance with ORNL SBMS Procedure, “Working With Non-Ionizing Radiation”; controls include surveys of magnetic fields, hazard warning postings, access restrictions for pacemaker wearers.

Risk Assessment Following Mitigation:

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	( ) Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	**( ) High**	**( ) Medium**	**() Low**	**(X) Extremely Low**

Is the mitigated hazard adequately controlled by existing laboratory policies? Y/N Yes

If no, roll up into SNS Accelerator Safety Envelope (ASE).

Table 4. Qualitative Risk for Laser Hazards in nEDM.

Facility Name: FNPB External Building
System: nEDM
Subsystem: Central Detector System
Hazard: Lasers

Number: nEDM-3

Event	During alignment or commissioning a worker views the Kerr effect laser.
Possible Consequences, Hazards	Worker blinded.
Potential Initiators	Failure to wear PPE, follow established procedures.

Risk Assessment Prior to Mitigation:

Note: Refer to figure 2 for an explanation of consequence, frequency, and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	(X) Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	**( ) High**	**(X) Medium**	**( ) Low**	**( ) Extremely Low**

Hazard Mitigation	In accordance with ANSI Z136.1-2000 controls include protective eyewear, equipment specific operating procedures, and training.

Risk Assessment Following Mitigation:

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	( ) Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	**( ) High**	**( ) Medium**	**() Low**	**(X) Extremely Low**

Is the mitigated hazard adequately controlled by existing laboratory policies? Y/N Yes

If no, roll up into SNS Accelerator Safety Envelope (ASE).

Table 5. Qualitative Risk for Oxygen Deficiency Hazards in nEDM.

Facility Name: FNPB External Building Number: nEDM-4
System: nEDM
Subsystem: Cryovessel
Hazard: Oxygen Deficiency

Event	Worker inside FNPB External Building when cryogen is released.
Possible Consequences, Hazards	A person unknowingly entering the area could be rapidly overcome without warning leading to death or permanent disability.
Potential Initiators	Loss of insulating vacuum on nEDM liquid helium storage vessel.

Risk Assessment Prior to Mitigation:

Note: Refer to figure 2 for an explanation of consequence, frequency, and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	(X) High	( ) Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	**(X) High**	**( ) Medium**	**( ) Low**	**( ) Extremely Low**

Hazard Mitigation	The cryogenic system will be designed In accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII and ASME Codes B31.1 through B31.7 (for piping systems). FNPB External Building designed to passively vent cryogens. Access controls and personnel trained to immediately evacuate upon visual (vapor cloud) or audible (pressure venting noise) evidence of a release, and Oxygen sensors with corresponding visual and audible alarms installed in strategic positions. Tested pressure relief valves.

Risk Assessment Following Mitigation:

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	( ) Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	**( ) High**	**( ) Medium**	**() Low**	**(X) Extremely Low**

Is the mitigated hazard adequately controlled by existing laboratory policies? Y/N Yes

If no, roll up into SNS Accelerator Safety Envelope (ASE).

Table 6. Qualitative Risk for Vacuum and Pressure Hazards in nEDM.

Facility Name: FNPB External Building Number: nEDM-5
System: nEDM
Subsystem: Neutronics, Cryovessel, external helium storage tank
Hazard: Vacuum/Pressure

Event	Structural failure of vacuum/pressure boundaries. Rapid gasification of cryogenic liquids.
Possible Consequences, Hazards	Failure of vacuum/pressure components could pose a potential health risk from flying objects.
Potential Initiators	Random failure. Failure caused by worker mistake or inadvertent striking contact with fragile window. Loss of cryogenic vacuum.

Risk Assessment Prior to Mitigation:

Note: Refer to figure 2 for an explanation of consequence, frequency, and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	(X) Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	**( ) High**	**(X) Medium**	**( ) Low**	**( ) Extremely Low**

Hazard Mitigation	1. Beam line vacuum components are designed to meet, withstand, or eliminate the full range of credible vacuum-related stresses. 2. Vacuum and pressure systems are reviewed during the beam line review process. 3. Vacuum components, except for neutron windows, are constructed of heavy-walled material, per ASME Boiler and Pressure Vessel Code, Section VIII,4-61 to minimize the threat of implosion when evacuated. 4. Neutron windows and feedthroughs are shielded to resist failure by casual blows or objects striking. 5. Hazardous access to large neutron windows is prevented by secondary enclosures or exclusionary zones interlocked to the PPS or a standalone SIS. Personnel access to such areas is allowed only when the chamber is vented with air and only when minor pressure differentials exist.

Risk Assessment Following Mitigation:

Consequence	( ) High	( ) Medium	(X) Low	( ) Extremely Low
Frequency	( ) High	( ) Medium	(X) Unlikely	( ) Extremely Unlikely
Risk Category	**( ) High**	**( ) Medium**	**() Low**	**(X) Extremely Low**

Is the mitigated hazard adequately controlled by existing laboratory policies? Y/N Yes

If no, roll up into SNS Accelerator Safety Envelope (ASE).

Table 7. Qualitative Risk for Elevated Work Hazards in nEDM.

Facility Name: FNPB External Building Number: nEDM-6
System: nEDM
Subsystem: Infrastructure
Hazard: Elevated Work

Event	Worker falls while atop 6m high apparatus.
Possible Consequences, Hazards	A worker falls from the top of the apparatus leading to death or permanent disability.
Potential Initiators	Violation of scaffolding boundaries without proper fall protection plan.

Risk Assessment Prior to Mitigation:

Note: Refer to figure 2 for an explanation of consequence, frequency, and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	(X) Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	**( ) High**	**(X) Medium**	**( ) Low**	**( ) Extremely Low**

Hazard Mitigation	In accordance with ORNL SBMS Procedure, “Walking/Working Surfaces and Fall Protection”; controls include engineered barriers, fall protection equipment, fall protection plans, and training.

Risk Assessment Following Mitigation:

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	( ) Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	**( ) High**	**( ) Medium**	**() Low**	**(X) Extremely Low**

Is the mitigated hazard adequately controlled by existing laboratory policies? Y/N Yes

If no, roll up into SNS Accelerator Safety Envelope (ASE).

Table 7. Qualitative Risk for Electrical Hazards in nEDM.

Facility Name: FNPB External Building Number: nEDM-7
System: nEDM
Subsystem: Central Detector Systems, Infrastructure
Hazard: Electrical

Event	Worker sustains shock from HV system. Worker sustains injury shutting off circuit breaker.
Possible Consequences, Hazards	Significant injury to worker.
Potential Initiators	Violation of procedures, including PPE.

Risk Assessment Prior to Mitigation:

Note: Refer to figure 2 for an explanation of consequence, frequency, and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	(X) Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	**( ) High**	**(X) Medium**	**( ) Low**	**( ) Extremely Low**

Hazard Mitigation	In accordance with ORNL SBMS Subject Areas “Electrical Work” and “Lockout/Tagout”, controls include PPE, equipment specific operating procedures, and training.

Risk Assessment Following Mitigation:

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely Low
Frequency	( ) High	( ) Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	**( ) High**	**( ) Medium**	**() Low**	**(X) Extremely Low**

Is the mitigated hazard adequately controlled by existing laboratory policies? Y/N Yes

If no, roll up into SNS Accelerator Safety Envelope (ASE).

Appendix A

Hazard Identification Summary Tables

Tables A-1–A-5 on the following pages contain the Hazard Screening worksheets used to identify potential hazards associated with the nEDM experiment that are detailed in this analysis.

Table A-1. nEDM Hazard Screening Worksheet #1.

Hazard Energy Sources and Materials		Applicable?
Electrical	Battery banks	
	Cable runs	X
	Diesel generators	
	Electrical equipment	X
	Hot plates	
	Heaters	1
	High voltage	2
	Locomotive, electrical	
	Motors	6
	Pumps	X
	Power tools	3
	Switchgear	
	Service outlets, fittings	X
	Transformers	
	Transmission lines	
	Underground wiring	
	Wiring	X
	Other	
Thermal	Bunsen burner, hot plate	
	Electrical equipment	X
	Furnaces	
	Boilers	
	Lasers	4
	Electrical wiring	X
	Welding surfaces	3
	Engine exhaust	5
	Heaters	1
	Steam lines	
	Welding torch	3
	Exothermic reactions	
	Other	
Open Flame	Bunsen burners	
	Torches	
	Pilot lights	
	Gas welding	3
	Other	

"X" marks hazards considered applicable

Footnotes

1. Resistive heaters will be incorporated into the apparatus to increase rate of cryogen boil-off during warm-up phases. Will not be accessible.
2. High voltages (500 kV) at low currents (10^{-9} A) will be present across the measurement cell w/stored energy (5–10 J)
3. Possible use during assembly, commissioning, and maintenance.
4. Class 3B lasers used to measure voltage applied to the measurement cell.
5. Potential from delivery trucks at loading dock and from manlifts during assembly, commissioning, and maintenance.
6. Secondary shutter.

Table A-2. nEDM Hazard Screening Worksheet #2.

Hazard Energy Sources and Materials		Applicable?
Pyrophoric (plutonium and uranium metal)		
Pyrophoric (Other)		
SC* (Nitric acid and organics)		
SC* (Other)		
Combustible materials		1
Uncontrolled chemical reactions		
Flammable	Flammable gasses	
	Natural Gas	
	Spray paint	
	Compressed flammable gasses	
	Propane	
	Paint solvent	
	Cleaning/decontamination solvents	2
	Gasoline	
	Flammable liquids	2
	Flammable mixtures	
	Other	
Explosive/ Pyrophoric	Explosive gas	
	Dynamite	
	Sodium	
	Hydrogen (batteries)	
	Primer cord	
	Electric squibs	
	Nitrates	
	Dusts	
	Peroxides	
	Caps	
	Plutonium/uranium	
	Potassium	
	Superoxides	
	Hydrogen/tritium	
	Propane	
	Explosive Chemicals	
	Other	

"X" marks hazards considered applicable

Footnotes

1. The shielding design for the apparatus is not yet defined, but it could contain hydrocarbon-based elements.
2. Small quantities of acetone and alcohol will likely be used during assembly, commissioning, and maintenance.

Table A-3. nEDM Hazard Screening Worksheet #3.

Hazard Energy Sources and Materials		Applicable?
Radiological material		1
Fissile material		
Nonionizing radiation		2
Ionizing Radiation	Fissile material	
	Radiography equipment	
	Particle beams	3
	X-ray machines	
	Critical masses	
	Contamination	
	Radioactive materials	1
	Radioactive sources	4
	Other	
Hazardous Materials	Alkali metals	
	Asphyxiants	5
	Acetone	X
	Fluorides	
	Lead	6
	Drowning	
	Asphyxiation	5
	Ammonia (& compounds)	
	Beryllium (& compounds)	7
	Chlorine (& compounds)	
	Trichloroethylene	
	Decontamination solutions	8
	Dusts and particles	
	Sandblasting particles	
	Metal plating	
	Herbicides	
	Insecticides	
	Bacteria	
	Viruses	
	Biological	
	Carcinogens	
	Oxidizers	
	Corrosives	
	Other toxics	
	Other	

"X" marks hazards considered applicable

Footnotes

1. Potential for contamination of beamline components and measurement cell possible.
2. Radio-frequency spin flippers, "dressing" coils, and neutron spin guide magnetic fields.
3. Radiation level can be elevated around beam tubes, especially if shielding is removed. If shutter is not closed, gamma and neutron radiation level can be high at the experiment location.
4. Test sources (alpha and beta) will be used during assembly, commissioning, and maintenance.
5. Large volumes of cryogens (helium and nitrogen) are used. Sudden release represents asphyxiant hazard.
6. Lead shielding use likely. Soldering during assembly, commissioning, and maintenance.
7. Thin beryllium foils likely to be incorporated into entrance window.
8. Acetone and alcohol likely used in small quantities for cleaning purposes during assembly, commissioning, and maintenance.

Table A-4. nEDM Hazard Screening Worksheet #4.

Hazard Energy Sources and Materials		Applicable?
Kinetic—Linear and Rotational (Friction)	Belts	
	Bearings	
	Presses	
	Grinders	
	Crane loads (in motion)	1
	Vehicles	2
	Rail cars	
	Fork lifts	1
	Carts	1
	Dollies	1
	Centrifuges	
	Drills	1
	Saws	1
	Shears	1
	Fans	
	Gears	
	Motors	3
	Power tools	1
	Other	
Potential (Pressure)	Gas bottles	4
	Gas receivers	
	Pressure vessels	7
	Coiled springs	
	Boilers	
	Heated surge tanks	
	Autoclaves	
	Furnaces	
	Stressed members	
	Steam headers/lines	
	Other	5,6,7

"X" marks hazards considered applicable

Footnotes

1. Use likely during assembly, commissioning, and maintenance.
2. Delivery trucks.
3. Secondary shutter.
4. Not explicitly anticipated, but possible use of compressed gases for some test apparatus.
5. Vacuum volume within neutron beamline and inside apparatus.
6. Pressure potential present in the form of cryogenic liquids (helium and nitrogen) which will release pressure when heated.
7. Liquid-helium storage tank (pressure vessel) outside nEDM building.

Table A-5. nEDM Hazard Screening Worksheet #5.

Hazard Energy Sources and Materials		Applicable?
Potential (Height/Mass)	Stairs	X
	Lifts	1
	Cranes	1
	Elevated doors	X
	Loading docks	X
	Hoists	1
	Elevators	
	Trucks	1
	Jacks	1
	Scaffolds and ladders	2
	Pits	
	Elevated work surfaces	2
	Mezzanines	X
	Other	
Firearm discharge (puncturing)		X
Nonfacility event (explosion)		X
Nonfacility event (power outage)		X
Nonfacility event (aircraft crash)		X
Nonfacility event (transportation)		X
Nonfacility event (fire)		X
Nonfacility event (other)		
Natural Phenomena	Earthquake	X
	Flood	
	Lightning	X
	Rain	
	Snow, ice	X
	Freezing weather	
	Straight wind	X
	Tornado	X
	Other	
Vehicles in Motion	Airplane	
	Helicopter	
	Train	
	Heavy construction equipment	
	Truck/car	1
	Forklift/lift truck	X
	Other	

"X" marks hazards considered applicable

Footnotes

1. Possible use during assembly, commissioning, and maintenance.
2. Detector apparatus is 6 m in height. Permanent scaffolds needed for access during assembly, commissioning, and maintenance.

Appendix B

FREQUENCY AND PROBABILITY GUIDELINES FOR HAZARD ANALYSIS

Initiating Events Category

Assigning frequency to one of the three major categories is judgment-based, aided as practicable with operating data and considering factors such as preventive maintenance (PM), which can affect failure frequencies. The frequency estimation does not have to be precise because each category encompasses two orders of magnitude.

Categories based on expert opinion or common knowledge of rate of approximate frequency of occurrence are defined as:

- Anticipated events are those that occur at least once in the life of any given facility. Frequency is in excess of 10^{-2}/a.
- Unlikely events are those that may not have occurred at any given accelerator but that have probably occurred at least once in accelerators. Frequency is between 10^{-2}/a and 10^{-4}/a.
- Extremely unlikely events are events thought to be possible even though they may never have happened at any accelerator facility. They must, however, be physically possible and credible events.
- Beyond extremely unlikely events are, in the professional judgment of responsible engineers and scientists, not credible events. Similar events must never have occurred in an accelerator facility (or else they would be in a higher frequency category).

Mitigating Actions Category

To understand effectiveness of mitigating actions, either administrative or automatic, it is necessary to assign an approximate conditional probability of success in the given circumstance. Given that the hazard-related initiating event has occurred, what is the likelihood of success for the mitigating action? Here are some example guidelines:

Automatic Action, Safety Instrumented System:

Between 0.99 and 0.999 for a SIL-2 (Safety Integrity Level 2) system, and between 0.9 and 0.99 for a SIL-1 system.

High-Integrity Non-Safety System:

Given the financial consequences involved, action of the Machine Protection System (MPS) is designed to provide success probability of between 0.9 and 0.99 for threats that it is designed to counter.

Personal Self-Protective Actions:

If the worker is specifically trained to evacuate on a given signal (oxygen deficiency hazard (ODH), radiation alarm, etc.), then it is highly likely (probability > 0.99) that the worker would evacuate within about 30 seconds.

If some diagnoses and thought is necessary (even for a trained worker), the worker may still evacuate with high certainty but only after a sufficient delay, e.g., two to five minutes.

Evacuation is highly likely even without specific training for unambiguous trouble signs such as obvious smoke or flames or severe earthquake shaking.

Even a loud, obvious alarm cannot be assumed to elicit quick evacuation without training. For example, personnel (e.g., riggers) in the building for a pickup or delivery cannot be assumed to evacuate without being told. In an incident that occurred several years ago, riggers covered their ears and stayed inside the building until specifically instructed to evacuate by one of the building personnel. Similarly, only ODH trained workers are assumed to evacuate following an ODH alarm.

Other Administrative Actions:

Other administrative actions must be evaluated on a case-by-case basis considering appropriate training and frequency of training. Administrative actions credited in an SNS hazard analysis must be consistent with the experience of personnel at other DOE accelerator facilities. Actions noted in the hazard analysis must be only those expected to come under strict management control and surveillance at a well-managed accelerator facility.