Prototype Energy Recovery Linac, Building 912

Safety Assessment Document

June 30, 2008

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1. Introduction

1.1. Scope

This document presents a basic understanding of the mission associated with the Prototype Energy Recovery Linac (ERL) in Building 912, the protections that are afforded the public and the workers' health and safety, and the protection of the environment from radiological hazards associated with electrons.

1.2. Basic Understanding of Prototype ERL Activities

The mission associated with the Prototype ERL in Building 912 is to study the requirements for an electron accelerator that may later be used to increase the performance of the Relativistic Heavy Ion Collider (RHIC). Figures 1.2.a through 1.2.h show the general layout and the plan views of functional areas at the Prototype ERL.

Figure 1.2.a Prototype ERL General Layout Inside Building 912

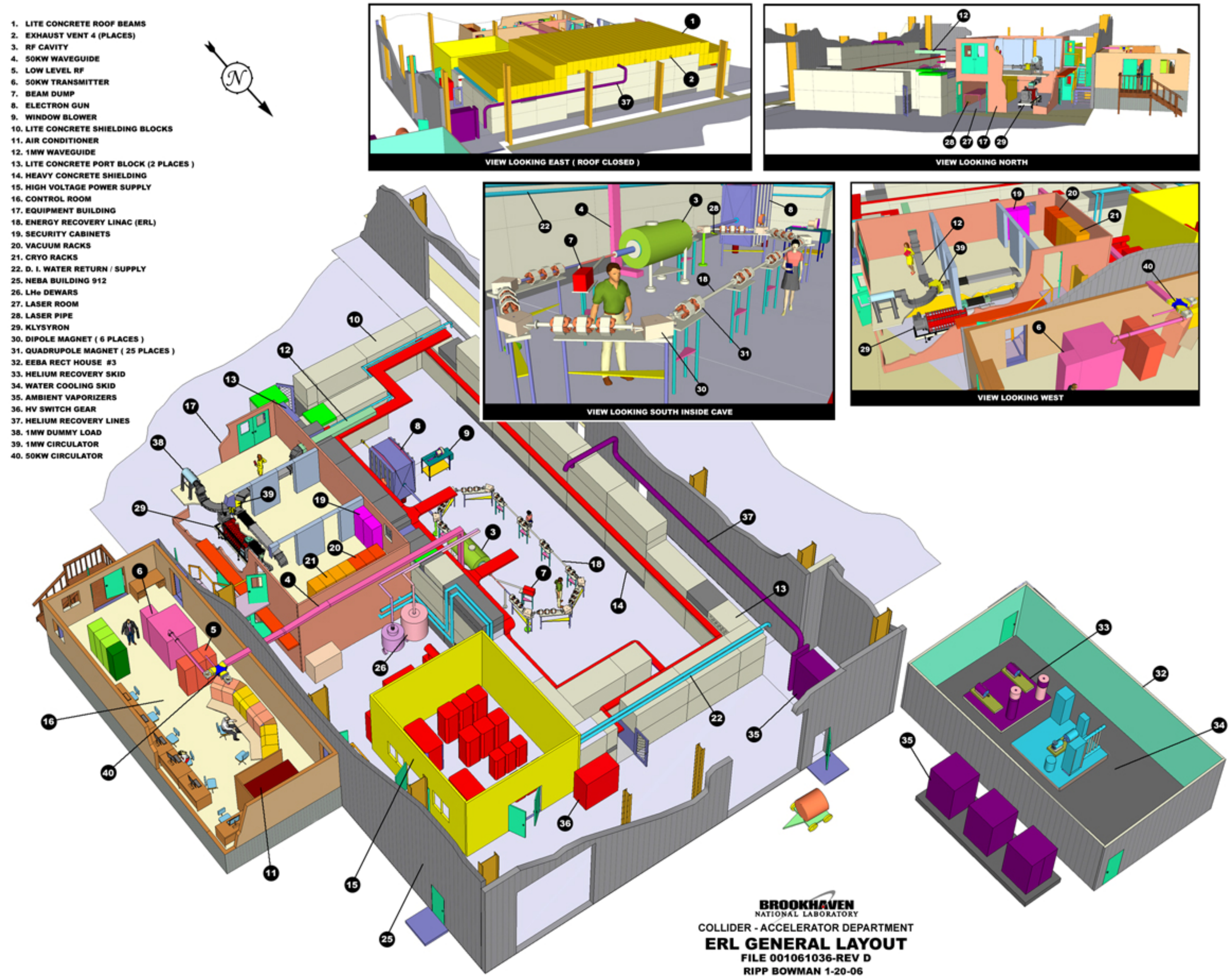


Figure 1.2.b Drawing of Prototype ERL in Building 912

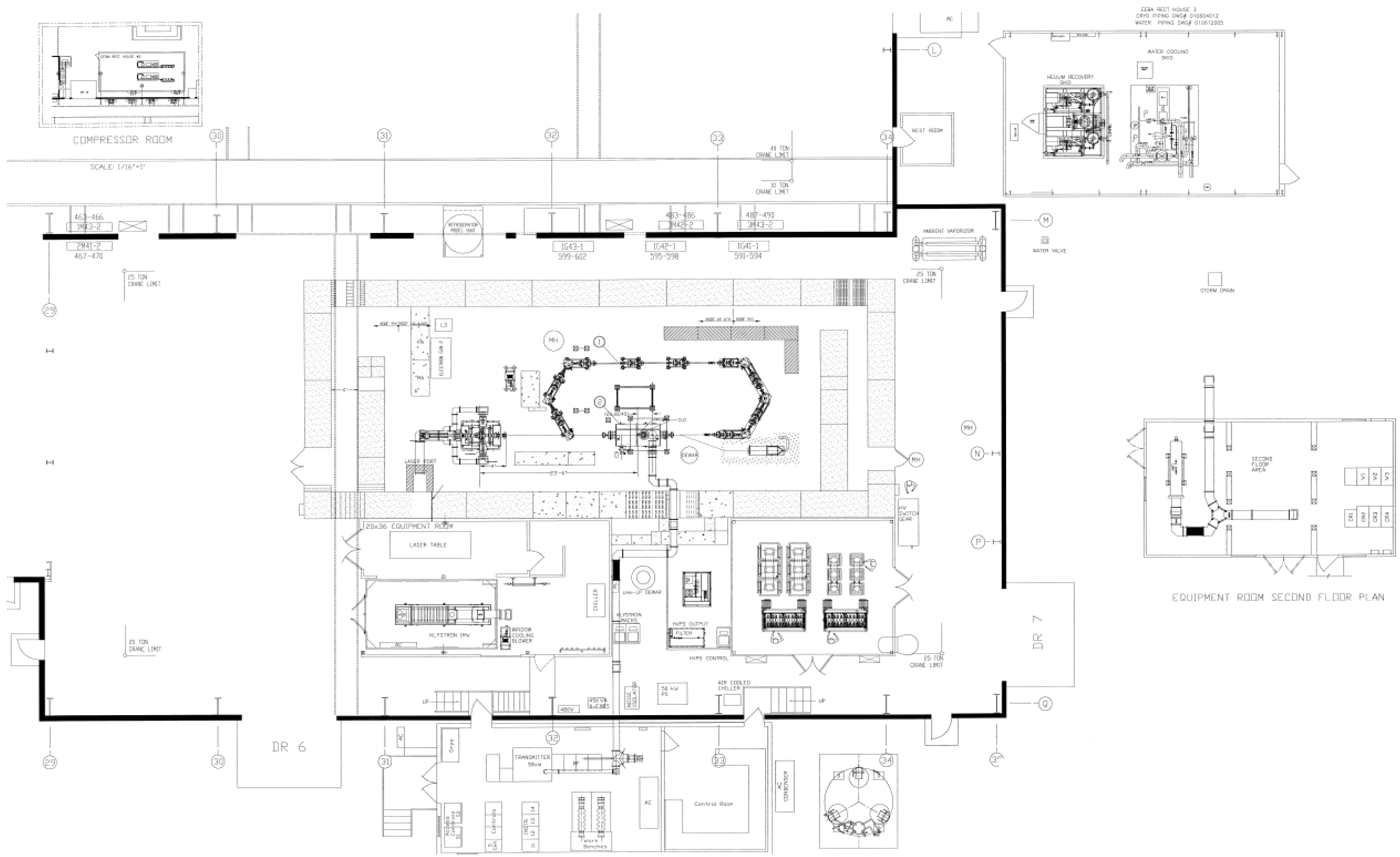


Figure 1.2.c Drawing of Prototype ERL Enclosure and Ring

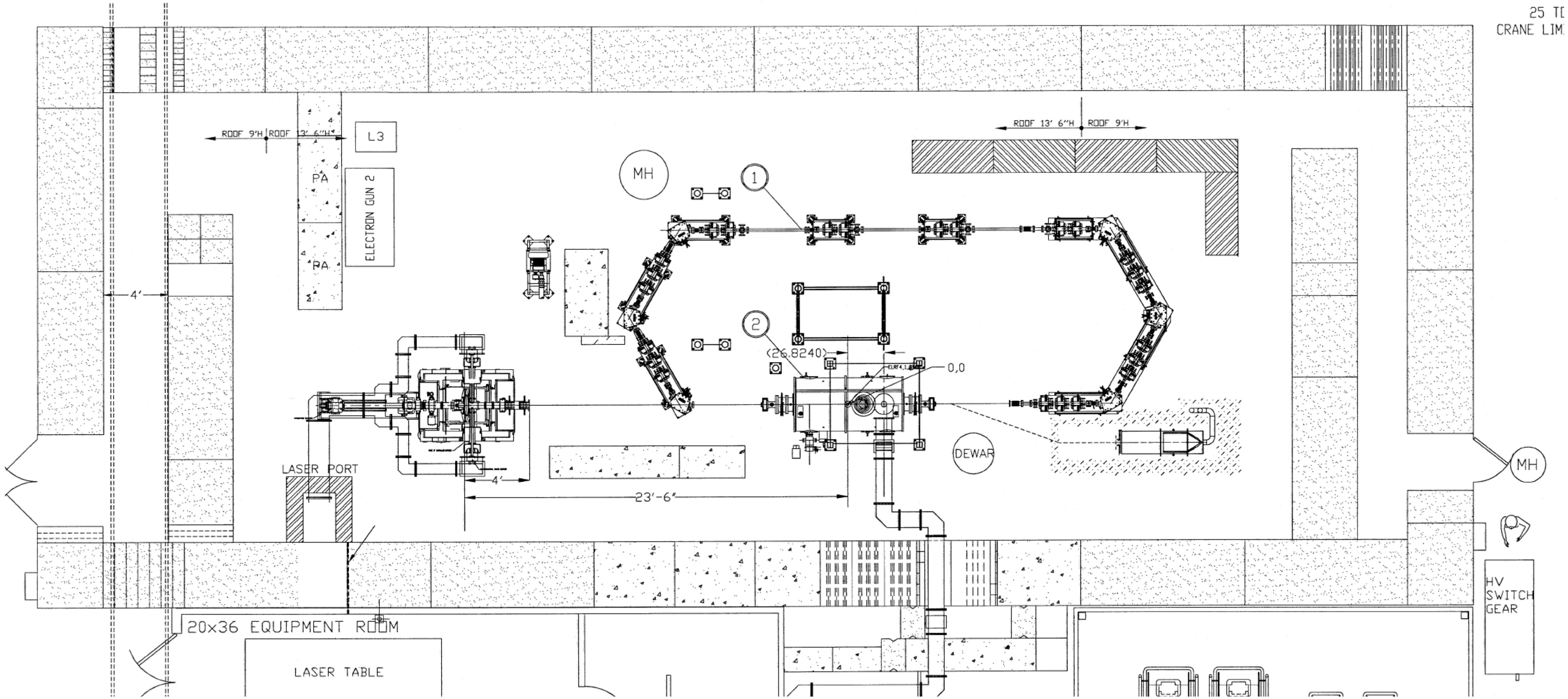


Figure 1.2.d Drawing of Prototype ERL Laser, Klystron and Power Supply Rooms

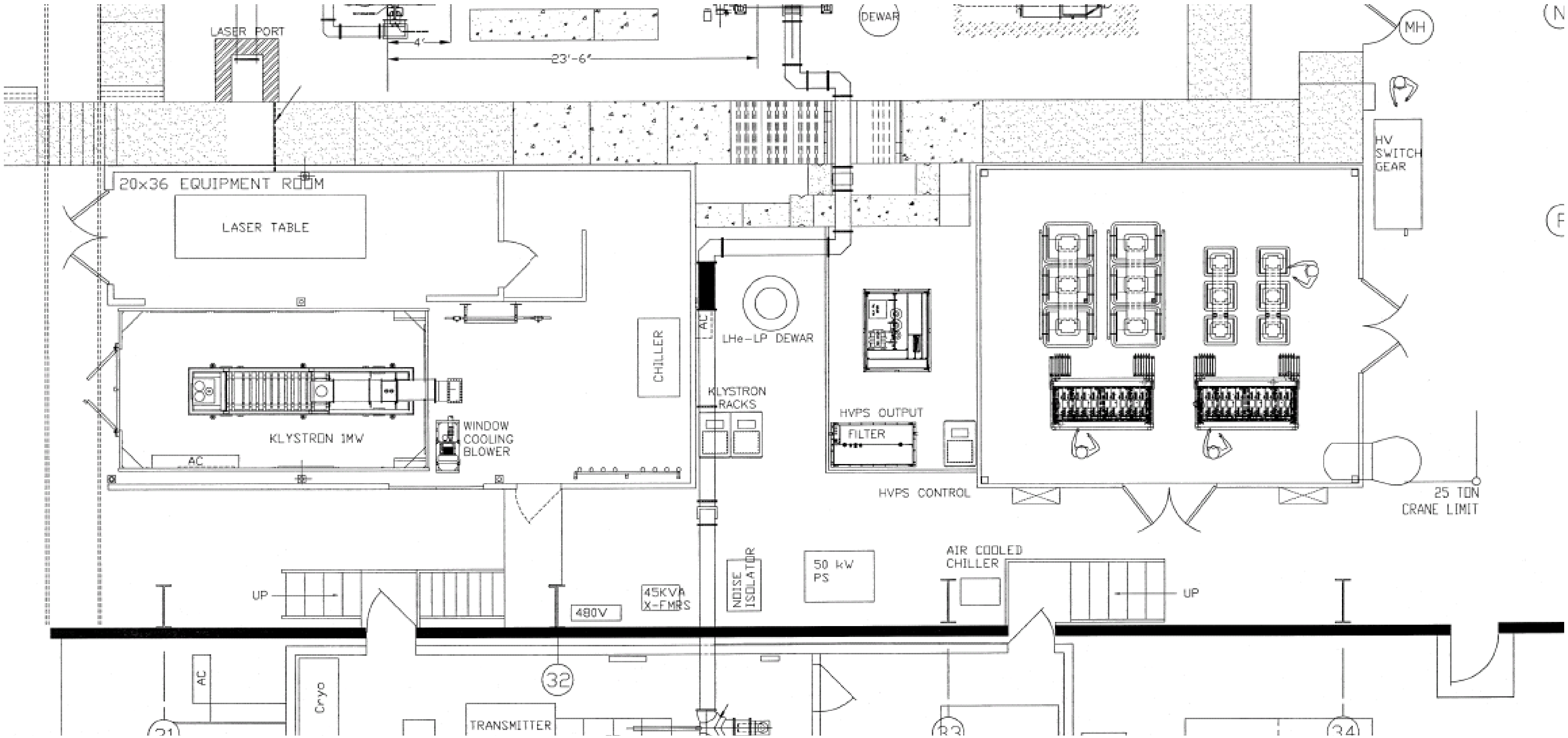


Figure 1.2.e Drawing of Prototype ERL Control Area and Nitrogen Storage Tank

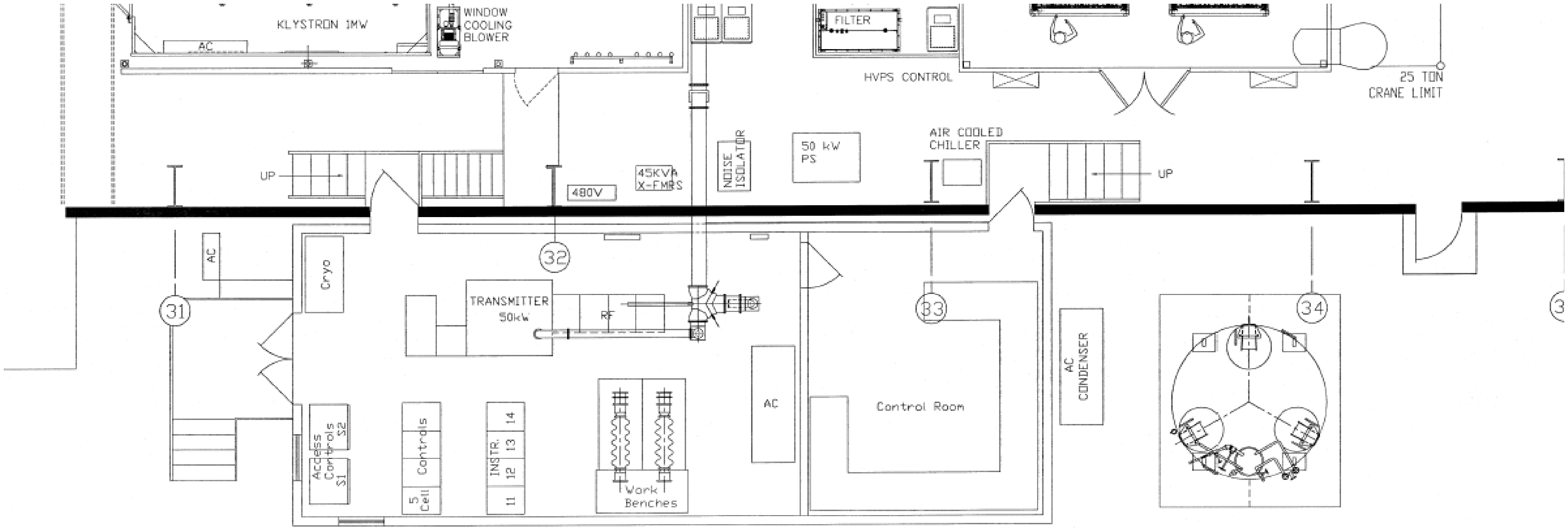


Figure 1.2.f Drawing of Prototype ERL Second Floor Level

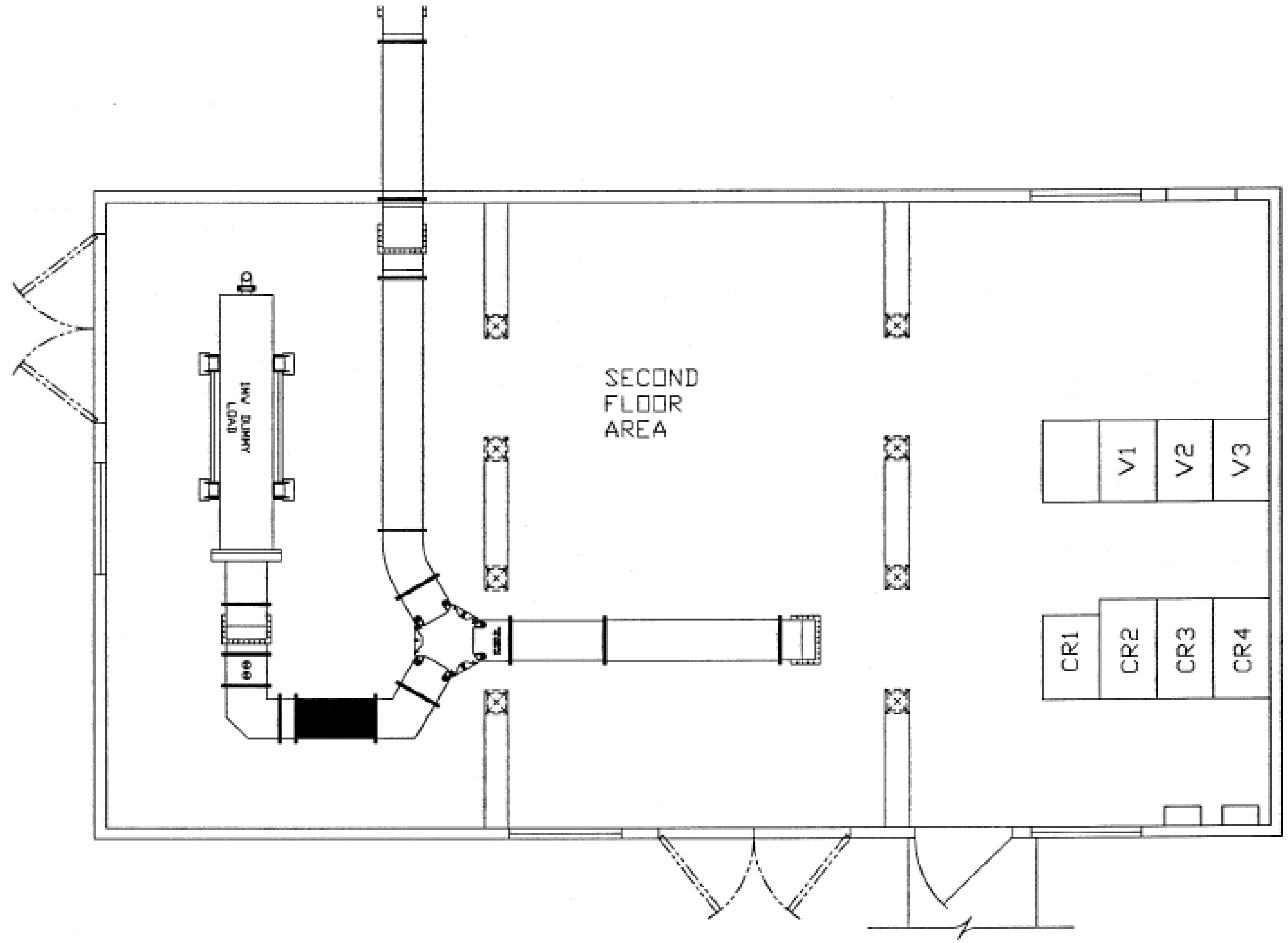


Figure 1.2.g Drawing of Prototype ERL Cooling Water Skid and Cryogenic Helium Recovery Areas

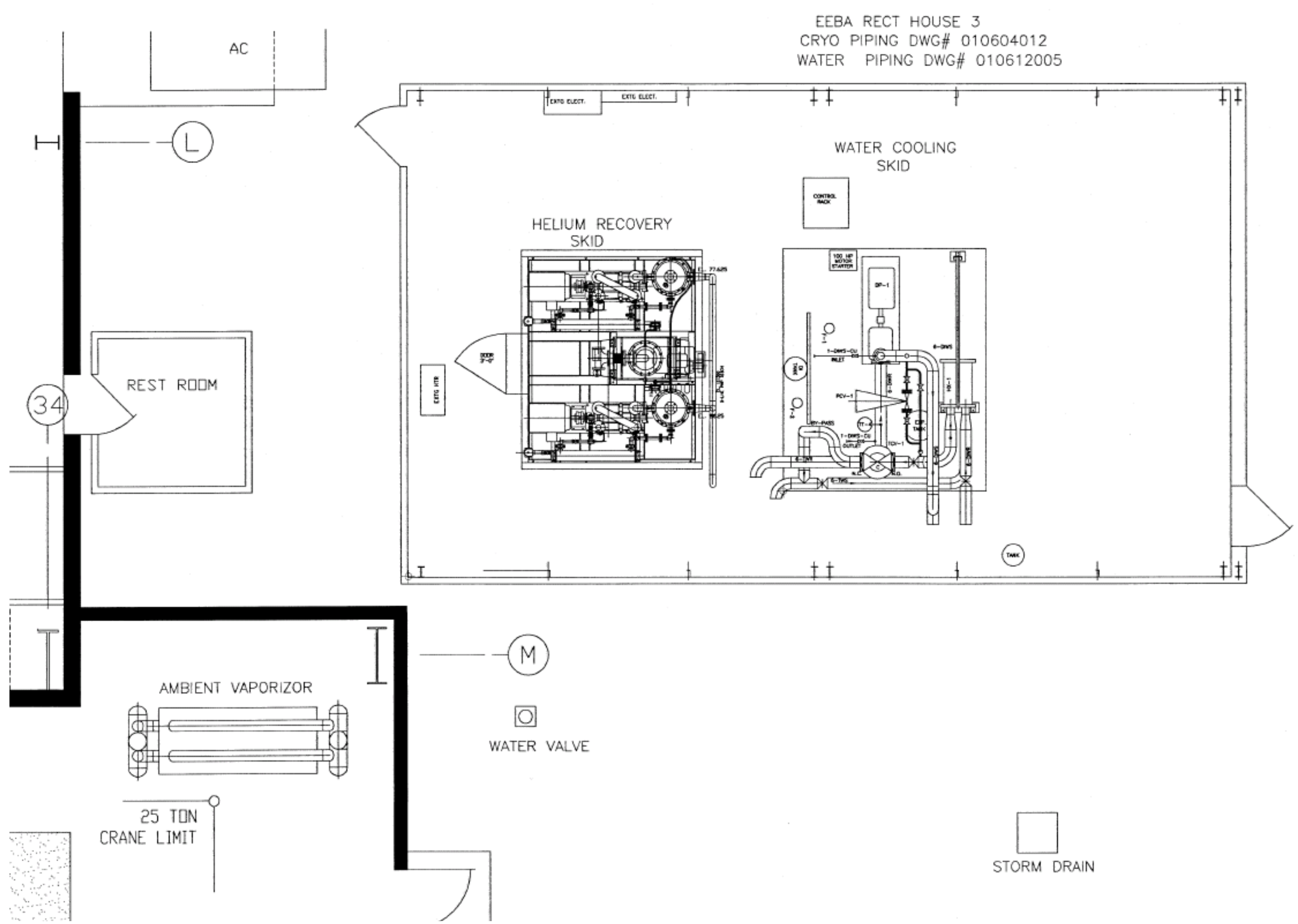
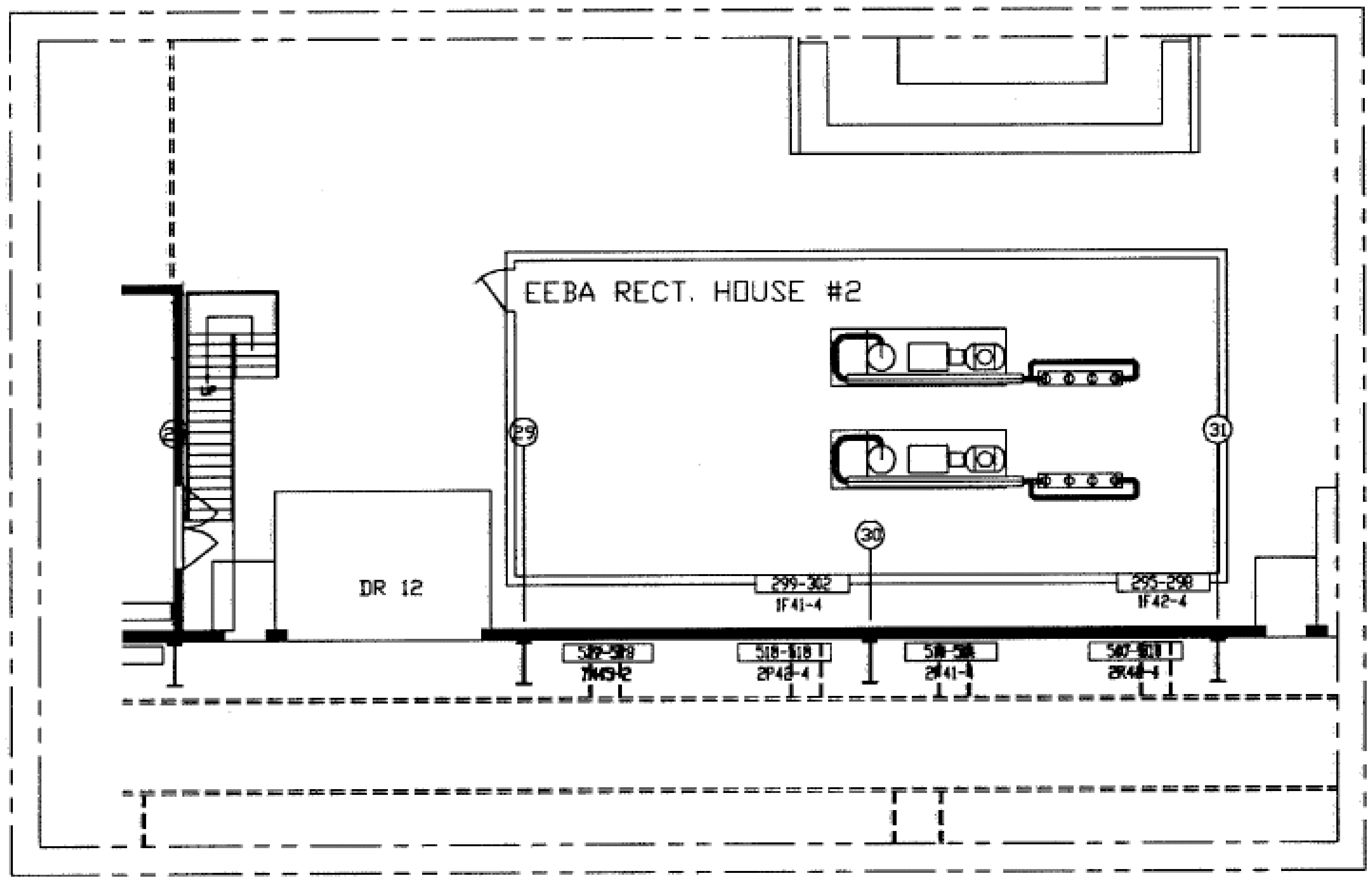


Figure 1.2.h Drawing of Prototype ERL Helium Compressor Room



In RHIC, the ion-beam bunch size can be further reduced to maximize luminosity[1] at the intersecting regions. Reduction of the energy of the motion of a bunch, and thus reduction of the size of a bunch, is termed "cooling." Cooling requires some friction force, and the friction force must be added. The most common methods are stochastic cooling and electron cooling. Electron cooling is the method to be studied with the Prototype ERL. This type of cooling will eventually be used to reduce the beam size in the RHIC ion storage rings. "Cold" electrons will be used to cool the "hot" ion beam. The result of cooling is a smaller beam size and a higher particle density, which leads to greater luminosity. It is estimated that increases in luminosity by a factor 10 will be achievable using electron cooling. Thus, collisions would occur at 10 times the present rate enabling physics processes to be studied that would otherwise be unachievable due to the practical constraint of time.

Electron cooling has been used in many ion rings before. However, the implementation of electron cooling in RHIC is more complicated than any existing cooler. RHIC's high beam energy requires electron energy of 55 MeV. While other coolers use a DC electron beam, the only way to make a cooling beam with 55 MeV is with a superconducting ERL. In order to verify out the eventual RHIC ERL design, the Collider-Accelerator Department (C-AD) built a smaller prototype of the ERL in Building 912. This Prototype ERL in Building 912 generates and accelerates an intense, 100 mA or greater, electron beam with energy up to about 25 MeV. The energy recovery aspect is due to the fact that the electron beam decelerates to few MeV

[1] Luminosity is expressed in units of cm^{-2} s^{-1} or b^{-1} s^{-1}. Luminosity is an important quantity that characterizes performance. For RHIC, luminosity is directly proportional to the revolution frequency, the number of bunches in one beam, the number of particles in each bunch in yellow ring, and the number of particles in each bunch in the blue ring, and it is inversely proportional to the cross sectional area of the bunches. If the number of particles crossing each direction per unit time remains unchanged, then smaller bunch cross-sectional-area leads to greater luminosity.

before being dumped, and most of its kinetic energy is recovered in an RF field. The overall plan is to test the concepts and stability criteria for very high current ERLs to be used at RHIC.

A brief description of the prototype system is as follows: An electron beam is created in a photo-cathode RF gun. At the exit of the gun, the electron energy is planned to be about 3.5 MeV. The beam is injected into a superconducting RF cavity, and accelerated up to 25 MeV. The beam is then passed through a "ring" and again enters the RF cavity. The beam passes into the RF cavity with a 180 degree phase shift relative to the accelerating phase of the cavity and the beam is therefore decelerated. With beam energy reduced to electron gun injection energy (3.5 MeV), a dipole magnet deflects the circulating beam into the beam dump.

1.3. Intentionally-Designed Protection Afforded the Public, Workers and Environment

Engineered controls include the Access Control System, fire-protection system, fixed-location interlocking area-radiation monitors and ionizing-radiation shielding. Administrative controls include posting, fencing, training and qualifications for radiation workers and visitors. Additional administrative controls include personnel dosimeters, Radiation Work Permits and As Low As Reasonably Achievable (ALARA) reviews of jobs and experiments when needed.

Radiation surveys using portable radiation monitors are used to verify the radiological controls at Prototype ERL on a regular basis. The limit on the beam in the Prototype ERL is such that exposure to individuals in Controlled Areas and in uncontrolled areas is designed to be less than the annual Brookhaven National Laboratory (BNL) dose limits that are listed in the

Accelerator Safety Envelope (ASE). Specific Prototype ERL beam limits are reviewed by the C-AD Radiation Safety Committee (RSC) before operations, and are also listed in the ASE.

The C-AD has embraced BNL's Integrated Safety Management System (ISM) as a basic protection for workers and experimenters. In order to guide operations and maintenance of the accelerator and associated systems at the Department level, an administrative control based on ISM and termed "Work Planning and Control" is used.

The BNL dose limits were derived from the administrative and engineered controls listed in 10CFR835 "Occupational Radiation Protection" and DOE Order 5400.5 "Radiation Protection of the Public and the Environment," which establish radiation protection standards, limits and program requirements for protecting employees and the public from ionizing radiation resulting from the conduct of DOE activities. These requirements are promulgated downward into BNL's RadCon Manual, and further into Departmental-level authorization documents and procedures.

1.4. Codes of Record

The following requirements are relevant to the Prototype ERL and are used to establish safety for the workers and the public:

- Design Codes
  - National Fire Protection Association (NFPA) 70, ''National Electrical Code'' (2005)

- NFPA 70E, ‘‘Standard for Electrical Safety in the Workplace’’ (2004)
- American Society of Mechanical Engineers (ASME) Boilers and Pressure Vessel Code, sections II, V, VIII, IX and X. including applicable Code Cases (2004)
- ASME B31 (ASME Code for Pressure Piping) as follows:
  - B31.3—2002—Process Piping (as applicable to the cryogenic system)
  - B31.9—1996—Building Services Piping (as applicable to the water cooling system)

- Consensus Safety Standards
  - ANSI Z136.1, ‘‘Safe Use of Lasers’’ (2000)
  - ANSI Z49.1, ‘‘Safety in Welding, Cutting and Allied Processes,’’ sections 4.3 and E4.3 (1999)
  - American Conference of Governmental Industrial Hygienists, ‘‘Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices’’ (2005)
- Federal Regulations
  - 10CFR835, Occupational Radiation Protection
  - 10CFR851, Worker Safety and Health Program
- DOE Orders
  - DOE Order 420.2B, Accelerator Safety
  - DOE Order 420.1A, Facility Safety, §§ 4.2 and 4.4
  - DOE Order 414.1C, Quality Assurance
  - DOE Order 5480.19, Conduct of Operations
  - DOE Order 5400.5, Radiation Protection of the Public and the Environment

- DOE Order 450.5, Environmental Protection Program
- DOE Order 435.1, Radioactive Waste Management
- DOE Order 243.1, Records Management Program
- DOE STD-1020-2002, Natural Phenomena Hazards Design And Evaluation Criteria For Department Of Energy Facilities

2. Summary/Conclusions

2.1. Results and Conclusions of the Analyses Provided In the SAD

The Prototype ERL accelerator is a facility with negligible offsite impacts, with extractable beam that goes to a beam dump, two points of entry, one enclosure, multiple operators/users, and multiple active safety systems. In addition to being able to create radiation levels above 5 mrem/h, unique non-radiation hazards such as potential for oxygen deficiency (ODH) exist.

It is concluded that this accelerator is subject to DOE O 420.2B Accelerator Safety, and an ASE for routine operations must be approved at the local DOE site office.[2] Additionally, according to Table 1 in the DOE Accelerator Safety Order Guide, the Safety Assessment Document and the ASE are to be tailored, as needed, to address workplace/onsite hazards and demonstrate no more than negligible offsite impacts. These requirements are promulgated in BNL's Standards Based Management System (SBMS) Accelerator Safety Subject Area.

Offsite impacts or major on-site impacts are "negligible" due to the physical aspects of the Prototype ERL whereby it is dependent upon an external energy source; that is, electric power that can be easily terminated. The primary hazard is prompt ionizing radiation that is limited to regions where the beam is maintained and is in existence only when a beam is present.

[2] DOE Guide 420.2-1, 7-1-05, Table 1. Tailoring of Accelerator Safety Order Requirements

2.2. Comprehensiveness of the Safety Analysis and Appropriateness of the ASE

The Safety Assessment Document (SAD) for Prototype ERL areas is consistent with DOE Orders. The format for this SAD closely follows the prescription for an SAD given in the DOE Guide 420.2-1.

The smoke and heat detection system, the ODH system and the access control system are identified as personnel-safety significant. The sprinkler protection system is designed to protect equipment to ensure timely continuity of the research in the event of a fire.

The shielding policy is clearly stated (see Appendix 3, C-AD Shielding Policy). Optimization methods are used to assure that occupational exposure is maintained ALARA in developing and justifying facility design and physical controls. Models used for dose rate predictions are described in the SAD and are verified against actual measurements.

Significant occupational safety and health aspects and environmental aspects are identified and adequate controls are described.

The SAD clearly identifies the safety and health aspects of all portions of the facility including the accelerator itself, beam transport components and the support facilities. The organizational structure and Environment, Safety, Security, Health and Quality (ESSHQ) programs for commissioning and operating the Prototype ERL are adequately described.

2.3. Appropriateness of the Accelerator Safety Envelope

On the basis of the safety analysis documented in Chapter 4 of the Prototype ERL SAD, associated risk assessment forms in Appendix 6, and the negligible environmental impact of this facility, the ASE conforms to requirements set forth in the BNL SBMS Subject Area, Accelerator Safety.

3. Site, Facility and Operations Description

3.1. Environment Within Which the Prototype ERL is Constructed

The accelerator site location is characterized in the following paragraphs. Information addresses adjacent facilities that may impact Prototype ERL safety or operations. The treatment of site geography, seismology, meteorology, hydrogeology, and demography would be duplicative of analyses performed in compliance with National Environmental Policy Act (NEPA) documents and the C-AD SAD.[3] Thus, it is not repeated here.

3.2. Prototype ERL Characteristics Related To Safety

The specific Prototype ERL characteristics related to safety include:

- A formal conduct of operations program that uses procedures, work planning and authorizations for all work
- Safety features and safety markings on equipment (e.g., pressure relief valves, burst disks, ground-fault alarms, ventilation, Underwriters Laboratories (UL) marks, American Society of Mechanical Engineers (ASME) code stamps, etc.)
- Safety limits and safety envelopes for routine operations
- Access to hazardous enclosures using interlocks for non-ionizing and ionizing radiation protection
- Access to hazardous enclosures using Kirk Locks and Lockout/Tagout (LOTO) for electrical protection

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[3] C-AD Safety Assessment Document, http://www.rhichome.bnl.gov/AGS/Accel/SND/c-a_sad_and_ase.htm

- Radiation shielding to control routine and fault levels of ionizing radiation
- Magnetic field shielding and warnings to protect workers who have medical implants
- Configuration controls for Prototype ERL drawings and equipment locations
- Formal design reviews and formal safety reviews for either new equipment or modifications to existing equipment
- Containment of non-ionizing radiation, such as laser and RF, within enclosures
- Continuous monitoring and alarms for fire, smoke, ODH, water leaks and ionizing radiation
- Certified hoists, cranes and rigging equipment
- Materials, welds, welding inspections, and pressure tests for pressurized equipment that meets pressure safety requirements in 10CFR851
- Trained and qualified staff for accelerator operations and maintenance activities
- Testing and calibration of safety related equipment and monitors

These characteristics that are related to safety are described in more detail in the sections that follow.

3.3. Management Methods Used In Operating the Prototype ERL Accelerator Facility

The C-AD is administered and organized to assure safe operation in accomplishing its mission. Its mission is to:

- Excel in environmental responsibility and safety in all department operations
- Develop, improve and operate the suite of accelerators used to carry out the program of accelerator-based experiments at BNL

- Support the experimental program including design, construction and operation of the beam transports to the experiments plus partial support of detector and research needs of the experiments
- Design and construct new accelerator facilities in support of the BNL and national missions.

In meeting its mission, the C-AD is under a formal Conduct of Operations Agreement with the Department of Energy.[4] The documentation that is used to comply with this agreement is the C-AD Operations Procedure Manual, called the Collider-Accelerator OPM, which specifies key procedures, chain of command, authorized personnel and other operational aspects.[5] Because it is capable of stand-alone operations, the Prototype ERL has a supplemental Conduct of Operations Agreement.[6] To take advantage of existing C-AD practices and systems, Prototype ERL procedures are in the C-AD OPM. The management that is used to assure that Prototype ERL personnel are qualified in safe operations is the C-AD management.[7] Prototype ERL operations personnel are qualified via a training program, including formal examinations, to certify operational qualifications where appropriate.

Only authorized Department personnel operate the Prototype ERL.[8] Direct daily supervision of shift operations is the responsibility of the on-duty Prototype ERL Operator in Charge. All Operators are authorized to shut down the Prototype ERL whenever an unsafe condition arises, or whenever they think that continued operation is not clearly safe. They are also authorized to take any other corrective safety- or environmental-protection-action as

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[4] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm Conduct of Operations Agreements
[5] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm Operations Procedure Manual
[6] Prototype ERL Conduct of Operations Agreement
[7] http://www.rhichome.bnl.gov/AGS/Accel/SND/OrgChart/OrgChart.pdf, see Chair's box on chart.
[8] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/opm_chapter_1.htm, see OPM 1.1.

indicated in the Collider-Accelerator OPM. All scheduled operational-related maintenance is done with the authorization of the Prototype ERL Operations Supervisor and the C-AD Maintenance Coordinator, with the work-control authorizations prescribed in the Collider-Accelerator OPM and with the knowledge of the on-duty Prototype ERL Operator in Charge.

The role, responsibility, accountability and authority statements (R2A2s) establish the expectations and duties of Prototype ERL managers and staff for carrying out the work consistent with external and internal requirements.[9]

Subject Areas are BNL documents that contain basic requirements and guidelines that apply to a broad group of staff across BNL.[10] Subject Areas were developed to support the implementation of national and consensus standards. In the case of the Prototype ERL, the basis for operations is defined in the Prototype ERL Conduct of Operations (ERL CO) agreement, the Prototype ERL SAD and ASE. Subject Area requirements, where applicable, have been flowed down into these documents.

Prototype ERL operations and maintenance procedures include task- or group-specific procedures that are used to implement C-AD management practices. The C-AD ESSHQ Division ensures that Prototype ERL operations and maintenance procedures are current and that they are in conformance with Laboratory-level governing documents, such as the Prototype ERL SAD, and the DOE approved Prototype ERL ASE.

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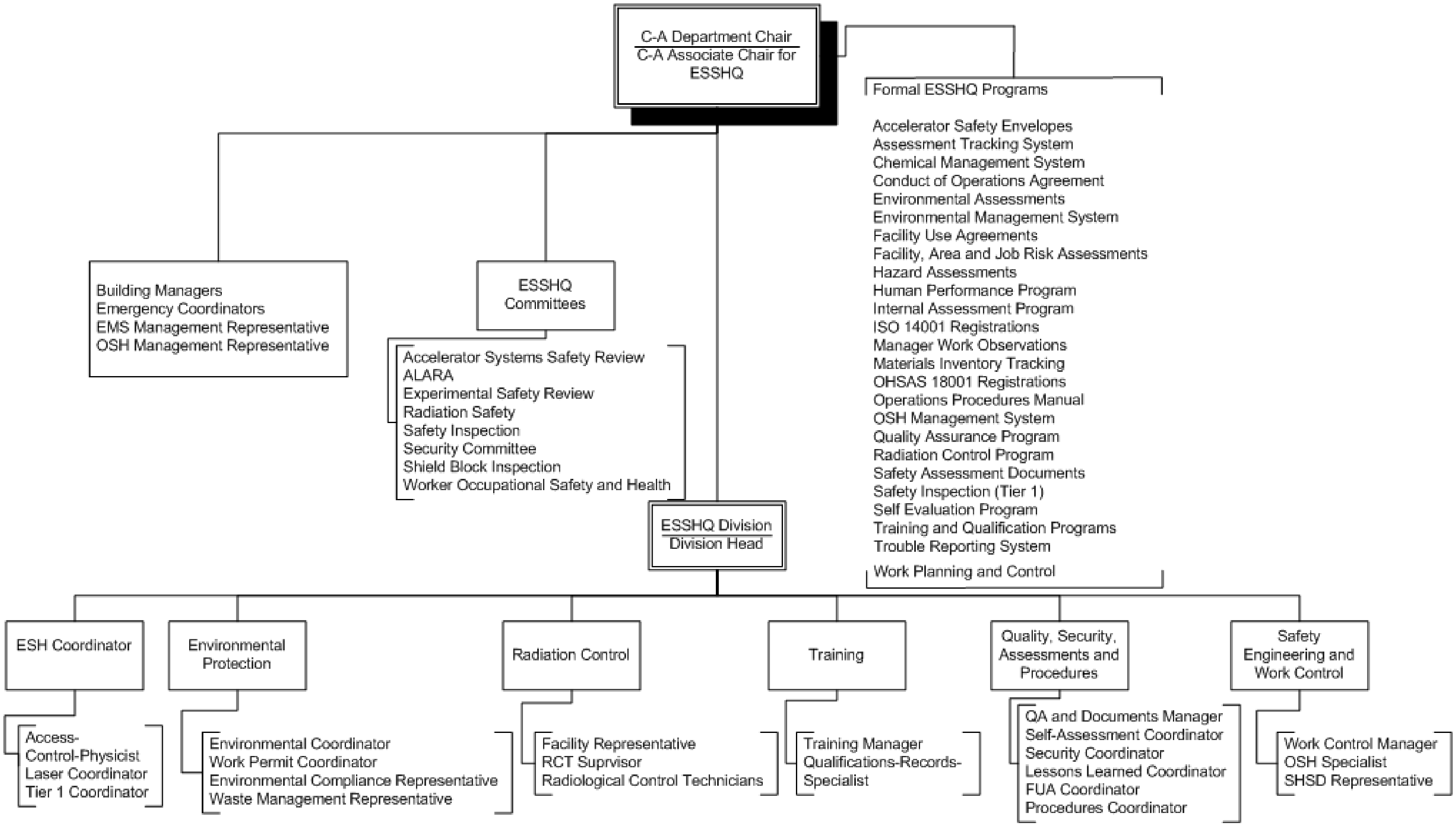
[9] https://sbms.bnl.gov/ R2A2 Subject Area
[10] https://sbms.bnl.gov/ Subject Areas List

The C-AD ESSHQ programs that cover Prototype ERL operations are indicated in Figure 3.3.a. The Associate Chair for ESSHQ is a member of the C-AD Chair's Office. The Associate Chair's roles are to implement new or revised environmental, waste, security, safety, health, training, human performance and quality programs, to inform personnel on the status of ESSHQ, to establish clear and complete safety-related communications practices and to maintain existing ESSHQ programs. The overall approach is to integrate ESSHQ requirements into all work using procedures and practices that are designed to ensure a safe and healthy environment.

Figure 3.3.a Operations Programs for ESSHQ at C-AD



"Safety" encompasses safety, health and environmental protection including pollution prevention and waste minimization. DOE has identified five Core Functions to manage safety, and identified seven Guiding Principles for performing the five Core Functions. The BNL management system that includes the five Core Functions and seven Guiding Principles is termed "Integrated Safety Management (ISM)." BNL's management systems to implement ISM are located in the SBMS.[11] SBMS is on-line with links to all referenced documents. The SBMS satisfies the contractual requirement for documenting ISM related practices lab-wide.

The C-AD uses safety committees and ESSHQ staff to define the scope of the experiments or work, identify and analyze hazards and develop hazard controls. The ALARA Committee, Experimental Safety Review Committee, Accelerator System Safety Review Committee and RSC meet requirements established in SBMS. These Committees are composed of members of the C-AD, other BNL scientific Departments and members of the BNL Environment, Safety and Health (ESH) Directorate. These Committees operate under a system of formal procedures contained in the C-AD OPM.

Self-assessment and self-evaluation are carried out by managers by using the annual Management Review practice and by using Manager Work Observations throughout the year. Individual employees use the C-AD work planning and Safety Walk programs for self-assessment. Project physicists and Liaison physicists use the C-AD's Committees for project safety reviews and facility and experiment safety inspections. Formal procedures for conducting self-assessments and self-evaluations are listed in the C-AD OPM. Assuring self-assessments are properly implemented is the purview of the C-AD QA Group. The C-AD QA Group also

[11] https://sbms.bnl.gov/ Subject Areas List

tracks corrective actions resulting from self-assessments and self-evaluations via the Assessment Tracking System (ATS).[12]

Third-Party Certification of Management Systems for ESH

The Prototype ERL in Building 912, by way of BNL certification, employs third-party certification for its Occupational Safety and Health (OSH) management system (MS) and its environmental management system (EMS). The international OHSAS 18001 and ISO 14001 standards are consensus standards used for third-party certification of the OSHMS and EMS. Certification is the process by which a third party confirms, in writing, that an organization's management system meets the specified requirements in the standards. Successful certification means C-AD's OSHMS and EMS meet all requirements in the international standards. The certification body is a third party (non-BNL) organization that assesses management systems. This certification body is often referred to as a "registrar."

In addition to annual surveillance audits, when the certificate of registration expires, which is every three years, the certification body conducts a complete reassessment.

[12] http://ats.bnl.gov/ Assessment Tracking System

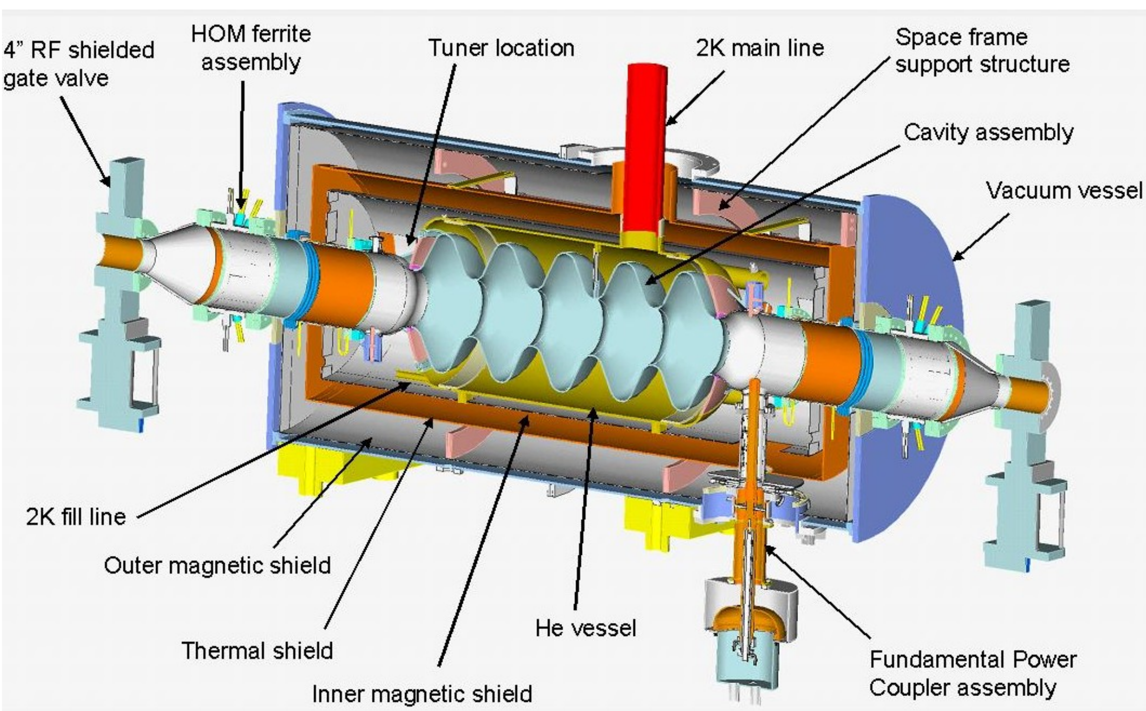
3.4. Design Criteria and As-Built Characteristics of Prototype ERL, Supporting Systems and Components with Safety-Related Functions

Superconducting RF Cavity

The superconducting linac cryomodule (Prototype ERL cryomodule) is shown in the figure below. These components are installed in the Prototype ERL facility in Building 912.

The superconducting linac cryomodule is an assembly used to accelerate electrons in the ERL. Its main element is a niobium structure called a cavity. The niobium cavity is shown in the figure below. It comprises 5 cells, to obtain a repeating pattern of the electromagnetic field in order to get efficient acceleration. The cavity resonates at a frequency of 703.75 MHz with microwave power that is fed through a port called the Fundamental Power Coupler. When cooled to liquid helium temperature, the niobium cavity becomes a superconductor, reducing the microwave losses so that high fields (up to 20 MV/m) can be set up in the cavity using a few 10's of watts of RF power. Naturally, such high fields can lead to hazardous acceleration of electrons over short distances. The high fields also cause field emission of electrons from the surfaces of the cryomodule; electrons that are accelerated to various energies by these fields until they are stopped in their path, which then results in x-ray radiation.

The details of the cryomodule are shown in the next figure. The 5-cell niobium cavity assembly is enclosed in a titanium helium vessel. The cavity is equipped with a tuner, fundamental power coupler and beam pipes for bringing the electron beam in and out of the cavity. The beam pipes also serve as conduits for the non-fundamental microwave power generated by the beam passing through the cavity, what is called HOM (Higher Order Mode) power. The HOM microwave power escapes the cavity due to the doorknob shape of the end pieces of the cavity, and is dissipated as heat in ferrite assemblies outside of and on either side of the cryomodule. The cavity is maintained at liquid helium temperature by liquid helium brought into the cavity's helium vessel through a 2 K main line. To reduce cryogenic losses the cavity system is enclosed in a vacuum vessel equipped with a thermal shield, comprised of a metal envelope covered by Multi-Layer Insulation (MLI). The cavity must be maintained in a low ambient magnetic field while being cooled down, and for this purpose, there are two magnetic shields enclosing the cavity.



RF Systems for Superconducting Injector and Superconducting Cavity

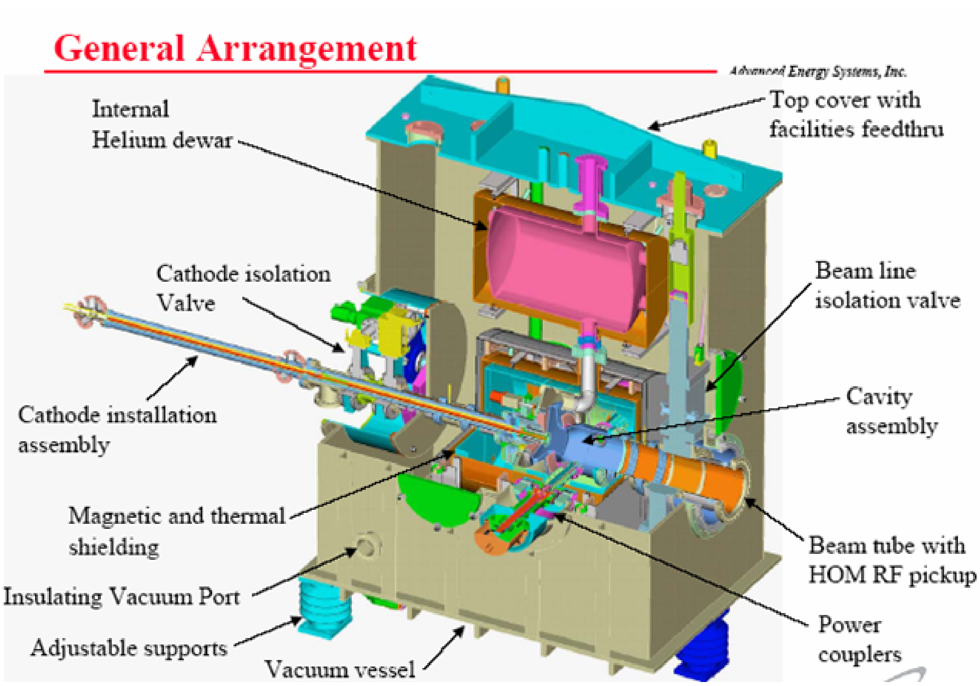
The Prototype ERL accelerator consists of a high brightness RF superconducting electron injector followed by a superconducting linac cryomodule used to accelerate electrons. The microwave power used to accelerate electrons in the superconducting electron injector is provided to the cavity by a 1 MW RF klystron delivered via two 500 kW fundamental power couplers at a frequency of 703.75 MHz. The microwave power used to accelerate electrons in the superconducting linac cryomodule is provided by a 50 kW continuous wave (CW) Input Output Controller (IOC) that also operates at a frequency of 703.75 MHz. The cavity resonates with microwave power fed through a port called the fundamental power coupler.

The exposure to non-ionizing RF radiation is controlled to prevent the radiofrequency power generated by the klystrons from providing a source of personnel hazard. Personnel cannot be near the 1 MW klystron source during operations due to a coordinated key system preventing access to its enclosure. Personnel cannot be near the RF power at the load since it is inside the accelerator enclosure, which is interlocked during operation via the ERL Access Control System (ACS). Between the klystron and accelerator structures, the RF radiation is enclosed in a waveguide. Additionally, outside the waveguide, the RF power is confined to the vacuum enclosure of the klystron and accelerator structures, which provides a redundant safety protection feature near the load or near the source. A break in the vacuum integrity in either of these would remove the insulation required to continue generating RF power. Finally, the RF radiation contained within the system's waveguides would be surveyed as described in Subject Area: Radiofrequency/Microwave Radiation, and it will be confirmed that ambient RF radiation is within the limits defined by the American Conference of Governmental Industrial Hygienists (ACGIH) and OSHA.

The emission of x-rays due to Bremsstrahlung from the 1 MW RF klystron is prevented via steel shield housing around the tube and tube base.

Injector System

The injector system for the Prototype ERL is shown schematically below. The injection system is made up of several major subsystems: the superconducting RF photoinjector, the cryogenic system, the cathode insertion device, and the RF system.



The photoinjector is an all niobium 703.75 MHz superconducting RF (SRF) cavity designed to operate at 2 K to produce and accelerate electrons. The microwave power to accelerate these electrons is provided to the cavity by a 1 MW RF klystron delivered via two 500 kW fundamental power couplers. As niobium is a superconductor at liquid helium temperatures, the surface resistance is effectively zero. This means that the microwave power fed to the cavity is almost exclusively delivered to accelerating the electrons, not heating of the niobium, allowing for CW high average current electron beam generation. This means that the 1 MW RF power can deliver a 0.5 A, 2 MeV electron beam to the Prototype ERL loop with minimal power dissipated to the liquid helium bath. During start up and conditioning, there may be dark current[13] generated in the injector. This hazard may produce x-rays when the electrons are accelerated; however, the accelerator enclosure adequately shields this radiation and access to the accelerator enclosure whenever the rf system is on is not allowed by the Access Control System.

The cavity is cooled to superconducting temperatures using 4 K liquid helium provided via external Dewars to the cryostat and internal helium Dewar shown in the schematic above. A large vacuum pump is then used to reduce the pressure over the liquid helium and thus reduce the temperature of the liquid helium to 2 K, the desired operating temperature.

The electrons are generated using a laser irradiated multi-alkali (CsK_2Sb) photocathode, which was produced in a custom deposition system designed to mate to the cathode installation assembly shown above. The laser system used to irradiate these cathodes is a Class IV laser system, with a repetition rate of ~87.75 MHz producing ~8 W of power in 10 ps pulses at 355 nm. The system consists of an oscillator locked to a master RF clock that drives the cavity, followed by a series of amplifier stages, pulse shaper/selector and harmonic crystals. The laser beam is transported to the photoinjector in enclosed beam pipes. The laser power will be low for

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[13] Dark current – relatively small current that flows through a photo-sensitive device even when no photons are entering the device.

initial alignment and increased gradually to full power. A Standard Operating Procedure for laser alignment, as per the BNL Subject Area, will be used.

Cryogenic Systems

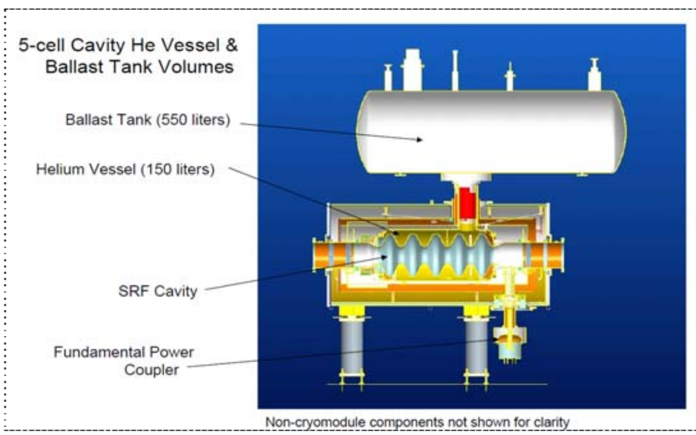
In addition to the liquid nitrogen storage vessel and helium compressor room, the cryogenic systems include:

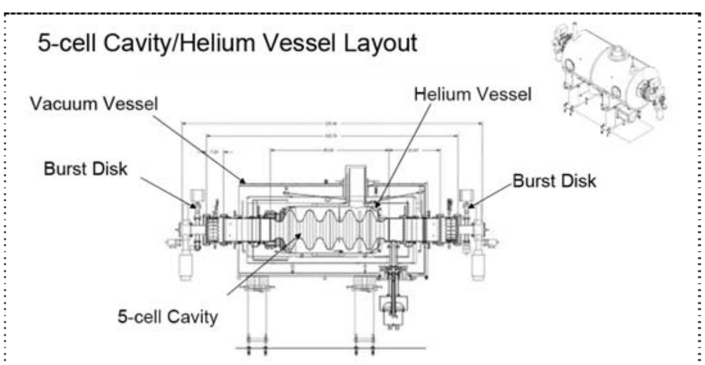
- Ballast tank - a liquid helium storage volume mounted above the 5 cell cavity; its purpose is to provide operational time at 2 K for the cavity
- 1.1 K Vacuum Pump - a vacuum pump for sub cooling the boiling liquid helium
- Warm Piping - ambient temperature piping associated with the Prototype ERL cryogenic system
- Transfer Line - cryogenic transfer lines to supply liquid helium to the 5 cell cavity
- Instrumentation - Pressure and temperature instrumentation and their associated I/O and hardware
- Insulating Vacuum System - Vacuum pump to maintain insulating vacuums
- Process Pressure Relief Valves – properly sized relief valves for the Prototype ERL cryogenic system

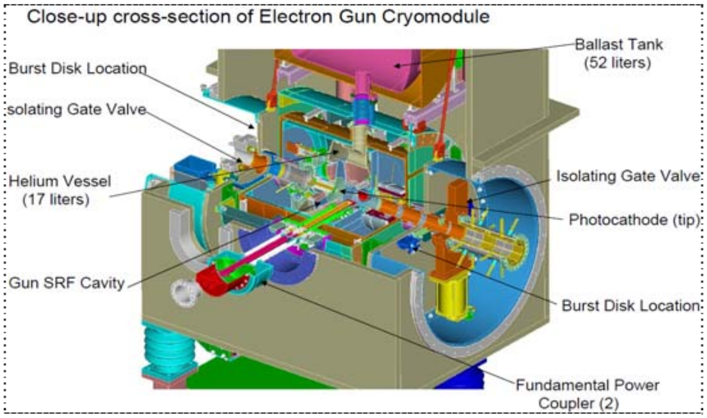
Non-stamped pressure vessels in the cryogenic systems were reviewed and approved by the BNL Pressure and Cryogenic Safety Subcommittee (PCSS). Specifically, the 5-cell cavity and the SRF gun were determined to be vacuum-rated pressure vessels that have the following equivalent protections, as per 10CFR851, since these vacuum vessels can be backfill pressurized in the event of failure:

- Design drawings, sketches, and calculations reviewed and approved by the PCSS
- Qualified personnel performed examinations and inspections of materials, in-process fabrications, non-destructive tests, and acceptance tests
- Documentation, traceability, and accountability for each vessel including descriptions of design, pressure conditions, testing and inspection

These vessels are depicted in the following figures that show the 5-cell cavity with its ballast tank and that show where burst disks have been installed.







Vacuum Systems

The vacuum systems consist of:

- Vacuum Chambers - stainless steel and aluminum vacuum chambers and beam pipes for Prototype ERL loop vacuum system.
- Vacuum Pumps and Valves – high-vacuum pumps for Prototype ERL loop vacuum systems.
- Vacuum Monitoring and Control System - vacuum gauges and Programmable Logic Controllers (PLC) for Prototype ERL loop vacuum system.

Magnets and Magnet Electrical Systems

The Prototype ERL magnet systems consist of dipole magnets that force the electrons to move in a circle or arc, and quadrupole magnets that act like a lens focusing the electrons to the center of the beam pipe. The Prototype ERL magnet systems include 4 injection-line dipoles, 1 dump magnet, and the ring magnets. The ring magnets include 25 quadrupoles and 6 dipoles.

The electrical power for the accelerator is distributed at 480 volts AC, 3 phases with a high-resistance grounded delta system. The equipment that requires the 480 V AC line voltage input includes ring magnet, dump magnet and injection-line magnet power supplies. Magnet electrical systems include the DC cable for these power supplies. The installation and operation of the power distribution system and the magnet electrical system is in accord with standard industrial practice for this type of equipment. At C-AD, this includes a remote, alarming ground-fault monitoring system.

Electron Beam Dump System

As its name suggests, the beam dump is where electron bunches end up while depositing energy unrecovered by the 5-cell cavity. The beam will be spread on the surface of a water-cooled, cylindrically shaped copper electron beam dump. Dimensions of this beam dump are roughly 62” in length and 19” in diameter. Spreading the beam over this large area is done to ensure that local boiling of the cooling water does not occur. The beam will be spread over this large surface area by magnetic field coils.

Beam Instrumentation

Beam instrumentation is functionally divided into subsystems: position monitors, current monitors, profile monitors, and loss monitors. The majority of the hardware and software is not available commercially off-the-shelf, but rather is designed and produced specific to the intended function. With the exception of loss monitors, all sensors are integral to the vacuum envelope.

None of the subsystems are interfaced to the personnel protection system. The beam-loss monitors are interfaced to the machine protection system, as are the current monitors. As operational experience is gained, portions of additional subsystems may be interfaced to the machine protection system.

Controls System

The ERL control system is based on the RHIC controls system. The controls system allows three basic modes of operation:

- Commissioning: low duty factor, about 100 Hz rep rate, one bunch per pulse
- RHIC mode: 9.37 MHz operation
- Navy mode: 700 MHz continuous

As designed, the RF cavity can only accelerate one bunch without suffering a droop in cavity voltage. When that initial bunch returns to the cavity after one turn, out of phase, all but a small amount of its energy is recovered. This allows a new bunch to be accelerated with the recovered energy.

A work-console composed of standard 19-inch racks with writing shelf attachments are provided in the facility control room. Each of 3 “seats” is equipped with a Linux workstation and 4 flat-panel monitors, configured as a single continuous display resource. Rack space is provided at the console for the access control system panel display and key-tree.

General purpose and project-specific application software for operating and monitoring the equipment and beam characteristics is used. Simple software tools for device control, sequencing, data logging, comfort displays, alarms, and e-logging are used. In addition, the RHIC *post mortem* system, that comprises automatic data recording by front-ends and associated display and summary tools after an abort, has been adapted for ERL.

The residual energy of the beam after recovering most of the energy will be about 1 MW. The beam is spread across the face of the beam dump to prevent thermal hotspots. A monitoring system monitors the spread and verifies proper operation as input to the fast-beam permit system; that is, a fast-beam inhibit response will be generated if beam spreading across the face of the dump fails.

Vacuum and water cooling monitoring for the dump is included in the vacuum and conventional systems. Beam current monitoring of the dump is provided by instrumentation. Beam-loss monitors consist of analog electronics, a comparator module and a channel by channel DC reference to monitor losses. All monitoring is interfaced with the fast-beam permit input.

Conventional Facilities

The conventional facilities service the needs of Prototype ERL with building space, environmental control (Heating, Ventilation, and Air Conditioning (HVAC)), cooling water, electric power, cable tray, radiation shielding, fire detection, rigging and survey services. Located inside the Northeast Building Addition (NEBA) section of Building 912 is the 4-foot thick concrete “Block House”, the Klystron Power Supply Building and a 2-story equipment building. The Block House requires rigging to open and close the roof to allow the larger pieces of experimental equipment to be installed or removed. The Klystron Power Supply Building was installed by an outside vendor. The equipment building houses security, vacuum and cryogenic control systems, magnet power supplies, a laser room and the Klystron. Outside of NEBA are the Experimental Control Room, two equipment buildings and Building 966, which is office and work space.

Cooling Water System

The Prototype ERL cooling water systems meet ANSI B31.9 Building Services Piping Code for pressure piping. Materials, components and workmanship are in compliance with this code. The system does not operate with pressure relief valves; however, the pumps are sized so as not to increase system pressure beyond the allowable stress for the piping, even if the cooling water stops circulating and the pumps continue to operate. The closed cooling water loops are without reliefs in order to prevent the possible release of low-level activated water to the groundwater.

The cooling tower has more than enough capacity to remove heat generated by all Prototype ERL operations. It is noted that the heat exchanger on the de-ionizer (DI) cooling loop can be expanded to increase heat removal capacity if that loop requires it. The initial planned system loads are shown in Table 3.4; however, actual Prototype ERL operations will determine the need for system changes.

Expansion tanks in this system are not ASME certified however expansion tanks are rated for 150 psi and are located on the low-pressure side of the cooling water system, which is about 20 psi. The ASME Code for Boilers and Pressure Vessels stamp is not required since the water in the tank has a design pressure less than 300 psi and a design temperature less than 210 ^{o}F. On the other hand, design and testing of the expansion tanks conforms to the ASME Code even though the expansion tanks are not stamped.

Table 3.4 Estimated Prototype ERL Cooling Water Heat Loads, Temperatures, Pressures

De-ionized (DI) Low Conductivity Water	Maximum Supply Temperature = 90 °F			
Component	Flow (gpm)*	kW Load**	Delta P	Delta T (°F)
Klystron Collector	385	650	10	11.5
1 MW Dummy Load	200	1000	5	34.2
Beam Dump	385	1000	10	17.8
50 kW Transmitter	20	80	50	27.3
50 kW Dummy Load	10	50	5	34.2
Chiller #1	50	55	10	7.5
10 Magnets @ 2kW each	20	20	50	6.8
Ferrite HOM (3)	15	20	50	9.1
FPC Gun (4 circuits)	5		50	
FPC 5-Cell (2 circuits)	5		50	
Solenoid Magnets (10 each at 2 gpm & 2 kW)	20	20	70	
He Recovery System	70	150	50	14.7
Total DI System Load	800	2045		17.5
DI System Capacity	820 gpm	1800 kW	120 psi	15 °F

* Klystron Collector and Beam Dump in series water flow.
**1000 kW heat load will either be at the 1 MW Dummy Load or at the Beam Dump.

Tower Cooled Components	Maximum Supply Temperature = 85 °F			
Component	Flow (gpm)	kW Load	Delta P	Delta T (°F)
DI Skid	800	2045	10	17.5
Tower Capacity	1000 gpm	3600 kW	200 psi	25 °F

Chiller #1	Maximum Supply Temperature = 86 °F			
Components	Flow (gpm)	kW Load	Delta P	Delta T (°F)
1 MW Circulator	20	50	70	17.1
Klystron Body 1	7	3.3	70	3.2
Klystron Body 2	7	4.8	94	4.7
Chiller #1 Load Total	34	58.1		11.7
Chiller #1 Capacity	45 gpm	60 kW	90 psi	9 °F

Air Cooled Chiller	Supply Temperature = 68 °F @ 6 kW Supply Temperature = 86 °F @ 7 kW			
Component	Flow (gpm)	kW Load	Delta P	Delta T (°F)
50 kW Circulator	7	2	87	2.0
Air Cooled Chiller Capacity	7 gpm	7 kW	90 psi	7 °F

3.5. Design Features That Exclude or Minimize Exposure to Hazards to As Low As Reasonably Achievable (ALARA) During Operation, Maintenance and Facility Modification

Superconducting RF Cavity

- Design reviewed by the C-AD RSC
- Design reviewed by the BNL PCSS
- Compliance with ODH Subject Area
- Burst disks and relief valves
- Access to area controlled with door interlocks
- Radiation shielding for beam loss and Bremsstrahlung
- Magnetic field shielding
- Configuration controlled drawings
- RF contained within vacuum enclosure

RF Systems for Superconducting Injector and Superconducting Cavity

- Design reviewed by the C-AD Accelerator Systems Safety Review Committee
- Access to area controlled with door interlocks
- RF contained within vacuum waveguide or enclosure
- 1 MW Klystron housed in steel shield to absorb Bremsstrahlung
- Configuration controlled drawings

Injector System

- Access to area controlled with door interlocks
- Protective housing for laser and laser shutter interlock
- Laser beam transported in pipe
- Configuration controlled drawings

- Radiation shielding for Bremsstrahlung
- RF contained within waveguide or enclosure

Cryogenic Systems

- Design reviewed by the C-AD Chief Mechanical Engineer
- Design reviewed by the BNL PCSS
- ODH Monitoring
- Ventilation
- Burst disks and relief valves
- Configuration controlled drawings
- The He tank: U-stamped[14]
- The LN2 tank: U-stamped
- Bulk oil tank: U-stamped
- Heat exchangers: U-stamped
- Oil removal demisters: U-stamped
- Carbon Bed: U-stamped
- Cryofab 1000 gallons liquid helium Dewar: U-stamped
- 1660S helium plant coldbox: BNL PCSS reviewed and accepted since this vacuum space can be backfill pressurized
- Ambient vaporizer: U-stamped
- Ballast tank: U-stamped

Vacuum Systems

- Design reviewed by the C-AD Accelerator Systems Safety Review Committee
- Design reviewed by the BNL PCSS where the vacuum space can be backfill pressurized

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[14] U stamp – a mark that indicates the pressure vessels was designed and fabricated according to regulations called out in 10CFR851.

- Allowable compressive stresses calculated using ASME Pressure Vessel Code

Electrical Systems

- Designs reviewed by the C-AD Chief Electrical Engineer
- Designed in compliance with NFPA 70 and NFPA 70E
- Ground-fault alarm system
- Lockout capability for all energized equipment
- Nationally Recognized Testing Laboratory (NRTL) or equivalent rated equipment
- Equipment grounding and cable tray bonding
- Enclosures or barriers over conductors
- Kirk-key locks for power supplies
- Co-axial cables with grounded shields for high-voltage cables
- Component labeling system

Electron Beam Dump System

- Design reviewed by the C-AD RSC
- Beam-dump temperature interlocks
- Access to area controlled with door interlocks
- Radiation shielding
- Configuration controlled drawings

Beam Instrumentation

- NRTL or equivalent rated equipment

Controls System

- NRTL or equivalent rated equipment

Conventional Facilities

- Certified hoists, cranes and rigging equipment
- Plant Engineering review and C-AD Chief Mechanical Engineer review of structures supporting heavy loads or structural changes to cranes or buildings
- Shielding requires lifting devices
- Cooling-water leak monitoring and alarms
- Fire, smoke detection and alarm systems
- Configuration controlled drawings
- Component labeling system

Access Control System

- Design reviewed by the C-AD RSC
- NRTL or equivalent rated equipment
- Local and remote radiation alarms
- Configuration controlled drawings
- Annual system testing

Fire Protection System

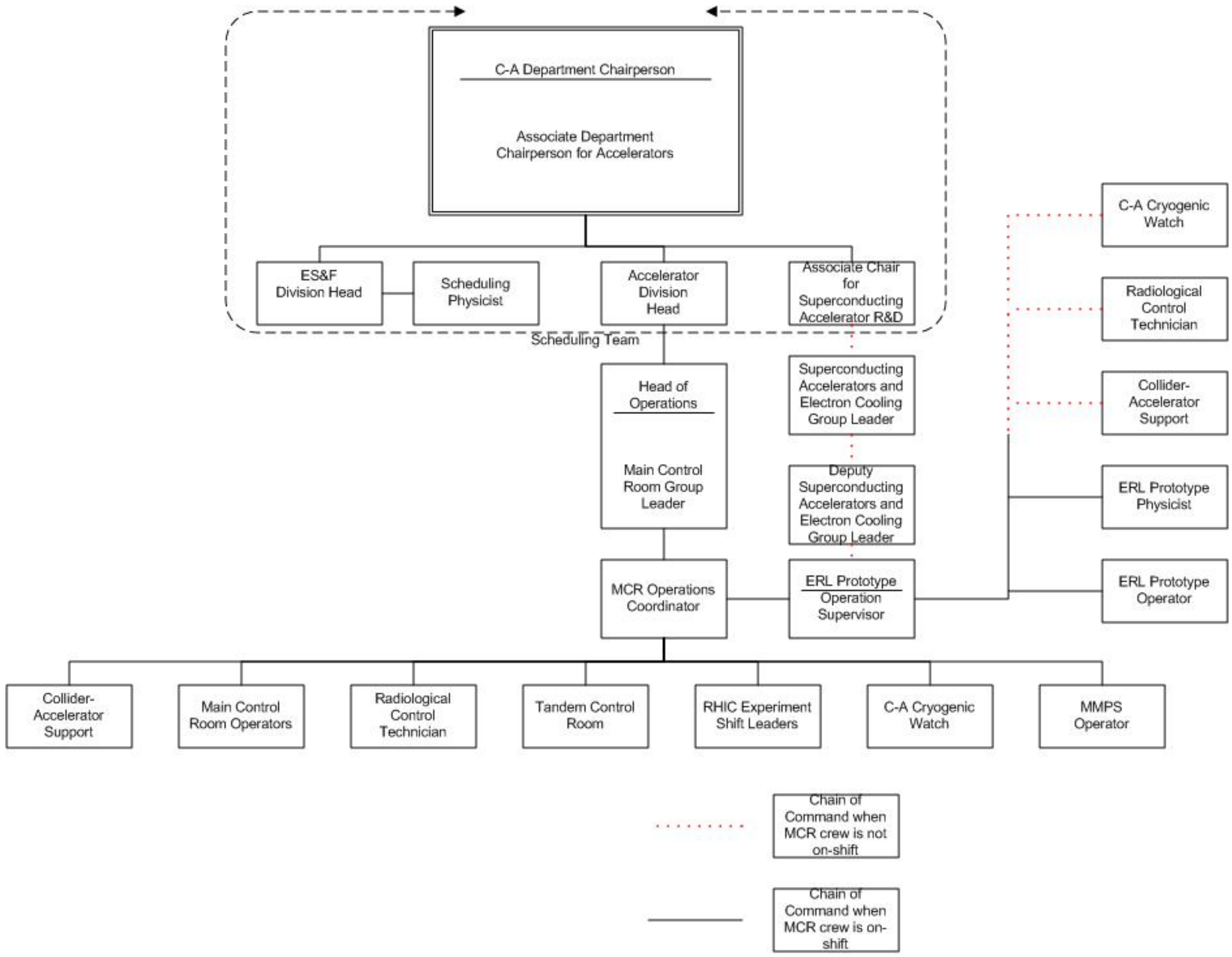
- Fire Hazards Analysis
- Configuration controlled drawings
- BNL Fire Protection Engineer review
- Smoke detectors
- Sprinklers
- Fire alarms
- Annual system testing

3.6. BNL, C-AD and Prototype ERL Organizational Structure

The Prototype ERL organization (see Figure 3.6) is a sub-set of the C-AD organization and the complete C-AD organization chart can be found at the C-AD website. Responsibility for the safe and reliable Operation of the Prototype ERL resides with the on-duty Prototype ERL Operator in Charge, who resides in the ERL Control Room. The Prototype ERL Operator in Charge is the Prototype ERL Operations Supervisor for the operating personnel, and the focus for all operations related questions. Personnel that are responsible for the day-to-day operations of the Prototype ERL are members of the C-AD Accelerator Division, the C-AD Experimental Support and Facilities Division (ES&FD), and the C-AD Controls Division. Additional personnel who support the operations belong to the C-AD ESSHQ Division, the BNL ESHQ Directorate and the BNL Plant Engineering Division.

Regular meetings are held between the ERL Operations Supervisor, the Main Control Room (MCR) Operations Coordinator when the MCR crew is on-shift, the Deputy Superconducting Accelerator and Electron Cooling Group Leader and group members of the various operating groups to discuss operational problems and possible corrective actions, safety, and other matters of concern. Since the MCR Operations Coordinator and the Prototype ERL Operations Supervisor share operations resources, the chain of command goes through the MCR Operations Coordinator when MCR crew is on-shift. In this way, all C-AD operations resources during an exigent or emergency situation at ERL will be coordinated, and authority clearly established.

Figure 3.6 Prototype ERL Operations Organization



3.7. Administrative Controls for Routine Operation and Emergency Conditions

Administrative controls for routine operation and emergency conditions are the Radiological Protection Program, which provides a means of controlling the radiological exposure received by facility workers and restricts access to High and Very High Radiation Areas, and the Occupational Safety and Health Programs, which provide protection against:

- Non-ionizing radiation
- Hazardous or toxic materials
- Electrical energy

- Explosive gases and liquids
- Oxygen deficiency
- Slips and falls
- Rotating equipment
- Noise
- Thermal energy
- Cryogenic temperatures
- Protracted/irregular hours
- Natural hazards such as insects

Administrative controls, including procedures and training, provide for worker protection for the following aspects of work:

- To control access to the accelerator
- To protect workers from radiological hazards
- To ensure authorizations for work are employed
- To ensure work is reviewed for hazards and controls
- To ensure waste minimization and pollution prevention
- To provide for worker feedback
- To ensure the evacuation of workers outside as required in response to a fire alarm
- To ensure water samples are obtained in the event of a water spill
- To ensure abnormal events are reported to the C-AD management

3.8. Critical Operational Procedures to Prevent or Mitigate Accidents

C-AD specific procedures in the following areas are in place to reduce the potential for an emergency at Prototype ERL. The C-AD OPM has a search feature that may be used to easily find procedures on:

- Handling and disposing of hazardous waste
- Radioactive waste disposal
- Controlling liquid, airborne effluents
- Enhanced work planning
- Lockouts and tagouts
- Access control system testing, sweep and reset requirements
- Conduct of operations
- Control room activities
- Maintenance
- Personnel protective equipment
- Conduct of experiment procedures
- Safety review
- Self-assessment

3.8.1. Emergency Preparedness

Procedures were developed to help operators and workers respond in an emergency to reduce the potential for environmental impact and to take actions to mitigate the event. These procedures can be found in C-AD OPM Chapter 3.

3.8.2. Configuration Control

Procedures were developed to help managers and engineers review technical changes to C-AD drawings and to approve specifications for new equipment. These procedures can be found in C-AD OPM Chapter 13.

3.9. Administrative Controls

Administrative controls are found in C-AD OPM Chapter 1: Policies for Authorization, Training, Environment, Safety, Procedures, Minors, Visitors and C-AD OPM Chapter 2: Conduct of Operations, Control Room Activities, LOTO, Maintenance, Work Planning.

3.10. Calibration and Testing

The C-AD OPM contains many procedures for calibration and testing. Most apply to the calibration and maintenance of measurement and test equipment used to verify conformance to prescribed high accuracy technical requirements during inspection, testing and research. However some procedures relate to calibration of safety related equipment, such as:

- ODH Field Calibration Procedure

- Equipment Calibration Procedures for Chipmunks (Area Radiation Monitors)
- Access Control System Test Procedures

Safety-related procedures in the OPM require literal compliance since deviation could trigger consequences that result in breaking the safety envelope of the accelerator or result in injury. Exceptions to literal compliance require review and written approval by the appropriate safety committee. Only the Department Chair or the Associate Chair for ESSHQ authorizes removal of safety related procedures from the OPM when such procedures are deemed no longer applicable.

3.11. Radiological, Worker Safety and Environmental Programs

BNL uses several programs to enhance worker safety and create a safe workplace. These programs are described as follows.

Integrated Safety Management integrates safety and work. It protects worker, public and environment. It is based on the simple "Plan, Do, Check, Act" concept. The ISM has five Core Functions for performing work and seven Guiding Principles to manage work. The five Core Functions focus on work planning and control for each specific task and are:

1. Define the scope of work
2. Identify and analyze the hazards
3. Develop and implement hazard controls
4. Perform work safely within controls
5. Feedback and improvement

The seven Guiding Principles are core beliefs about managing workers and/or projects safely and are:

1. Line management responsibility for safety
2. Clear roles and responsibilities
3. Competence commensurate with responsibilities
4. Balanced priorities
5. Identification of safety standards and requirements
6. Hazard controls tailored to work being performed
7. Operations authorization

In addition to promoting these functions and principles, BNL adheres to health and safety requirements in two federal regulations: 10CFR851 Worker Safety and Health, and 10CFR835 Occupational Radiation Protection. The requirements in these regulations have been flowed down through BNL's hierarchy of documents and practices and into Prototype ERL's operating procedures and training programs.

BNL also uses four voluntary programs to help meet the requirements of regulations, and to help implement the functions and principles of ISM. These programs are:

- OHSAS 18001 Occupational Safety and Health Management Systems Specification
- ISO 14001 Environmental Management Systems Specification
- Manager Work Observation
- Human Performance

The OHSAS 18001 and ISO 14001 are third party certification programs. The certification process functions in the following manner. BNL selects a registrar to assess its ESH management systems. If the auditors determine that the occupational safety and health management system conforms to the international OHSAS 18001 standard, or the environmental management system conforms to the international ISO 14001 standard, then the certification body issues a certificate of registration.

Manager work observations are periodically performed by managers, safety specialists and workers. Manager work observation is a process that takes managers, safety specialists and workers at all levels into the work areas where they have some responsibility, to observe the work and to talk with each other about safety at the job site. Managers are expected to have brief discussions with employees regarding their specific tasks during a specific job. The objective is to improve safety by reducing risk and eliminating injury. The approach emphasizes positive, 2-way discussions in which participants learn and try to define safer ways to work.

Human performance, in its simplest form, is a series of behaviors executed to accomplish specific task objectives. Behavior is what people do and say—a means to an end. Behavior is an observable act that can be seen and heard. It can be measured. If it can be measured, it can be changed. In the accelerator business, the "end" is that set of outcomes manifested by the complex of accelerators—the safe, reliable, and efficient generation of particle beams. To improve accelerator performance, human performance must improve.

Because of the human element, people will make mistakes despite the best efforts. Studies have shown that humans make an error approximately once every 3000 times they perform the same task. Therefore, behavior and its causes are extremely valuable as the pointers to improvement efforts. Excellent human performance leads to optimum accelerator performance partially by protecting the accelerator and personnel from the consequences of human error. To do so at BNL, a set of error-prevention practices are in place to anticipate, prevent, catch, and recover from human error. These practices are aimed at double checking and triple checking before a task is performed, which has the effect of reducing human error rates by two or three orders of magnitude.

3.11.1. Examples of Pollution Prevention and Safety Improvement

Examples of pollution prevention and safety improvement at C-AD resulting from implementation of ISO 14001 and OHSAS 18001 include:

- Over 1,000,000 person-hours worked without a lost-work day injury
- Savings of about 700 MW-hours per week of operations by improving efficiency of the cryogenics plant for RHIC
- Removal and disposal of PCB electrical devices
- Water use reduced by 25,000 gallons per month

3.12. Records Management

The Prototype ERL follows C-AD OPM 13.4.1 for Records Management, which in turn follows BNL's SBMS. The Prototype ERL Records Custodian is the C-AD Records Custodian.

The applicable design specification, procurement document, operation procedure, inspection/test procedure, BNL management system, or SBMS Subject Area, or regulation specifies the records to be generated, supplied, or maintained by Prototype ERL. Examples of records to be maintained include:

- Fault Studies and Logbooks
- Engineering Change Notices
- Interlock Tests Records
- LOTO Records
- Work Permits
- Training Waivers
- Equipment Ready Checklists
- Safety Review Committee Records
- Maintenance Records
- Audit Results
- Critiques/Occurrence Reports
- Nonconformance Notices

These examples are not the exclusive records to be kept. The actual list is found in C-AD OPM Chapter 13.

3.13. Tests to be Conducted at Prototype ERL

This Prototype ERL R&D program has goals to demonstrate continuous wave (CW) operation with average beam current in the range of 0.1 – 1 ampere, combined with very high efficiency of energy recovery. The heart of the facility is a 5- cell 703.75 MHz superconducting RF linac. The Prototype ERL provides a test-bed for testing issues of transverse and longitudinal instabilities and diagnostics of intense CW e-beam. The Prototype ERL R&D program is pursued by C-AD as an important stepping-stone for increasing the luminosity of the Relativistic Heavy Ion Collider (RHIC).

Furthermore, the Prototype ERL R&D program extends toward a possibility of using a 10-20 GeV ERL for future electron-hadron/heavy-ion collider, eRHIC. The specific goals of the Prototype are to:

- Test the key components of the electron cooler
- Test the key components of high current ERL based solely on superconducting RF (SRF) technology:
    - 703.75 MHz SRF gun test with 500 mA
    - High current 5-cell SRF linac test (one turn - 500 mA, two turns - 1 A)
    - Test the beam current stability criteria for CW beam currents ~ 1 A
- Test the key components and scalability for future linac-ring collider eRHIC with
    - 10-25 GeV SRF ERL for eRHIC
    - SRF ERL based FEL-driver for high current polarized electron gun
- Test the attainable ranges of electron beam parameters in SRF ERL

3.14. Test Equipment Design Criteria and Components Having Safety Functions

Access Control System

The ACS for the Prototype ERL facility uses PLCs as the basis for decisions made by the system. In order to provide the required dual independent protection, the area served by the ACS has two independent PLCs (A and B divisions). Each division independently provides full protection. All the input/output devices (gate switches, critical devices, etc.) are redundantly monitored by both PLC systems. In addition, redundant monitoring of radiation level and ODH concerns was incorporated in the safety system.

The operator interface to the ACS utilizes touch screen displays (flat panels) on a command network that is connected through a firewall machine to the separate divisions.

The Department's 'classification' scheme for all radiological areas at C-AD defines the nature and extent of the access/beam control systems. The ACS prohibits access or limits the radiation dose when the radiological areas are accessed. Table 3.2.2.1 in the C-AD SAD delineates the access, enclosure and minimum system requirements, for each C-AD 'classification,' and takes into account the potential levels of radiation during normal operations, and the potential increases in radiation levels with abnormal conditions.[15]

There are five basic design criteria for the ACS that applies to all C-AD beam enclosures:

[15] C-AD Safety Assessment Document, http://www.agsrhichome.bnl.gov/AGS/Accel/SND/c-a_sad_and_ase.htm

- Either the radiation is disabled or the related access control area is secured
- Only wires, switches, relays, PLCs and RSC approved active fail-safe devices are used in the critical circuits of the system
- The system is designed to be fail-safe
- Redundant critical devices are used to disable the beam and redundant interlocks are used to secure the area if the dose equivalent rate can exceed 50 rem/h
- If a beam fails to be disabled as required by the state of its related access control area, then the beam is disabled upstream; that is, the access controls have backup or what is sometimes termed “reach-back”

The RSC reviews and approves changes to the ACS. They approve the critical devices and they establish the conditions that the ACS must monitor. For example, they approve electric current in beam elements, the position of moveable beam-components or the position of access gates. The RSC establishes the alarm level and interlock level for Chipmunk area radiation monitors that may be interfaced with the ACS.

During commissioning periods for new or modified accelerator facilities, radiation studies are conducted by the RSC to verify the adequacy of the shielding, access control and radiological area classification. These studies are termed “fault studies.” That is, the calculated radiation levels are verified by direct radiation measurements, which confirm the appropriateness of the as-built ACS and as-built shielding, and the radiological area classifications inside and outside the facility.

Fire Detection System

Required fire protection design features are identified in the Fire Hazards Analysis (FHA). In many cases, various means are available to meet the general criteria required by the DOE Order 420.1. The following guidelines were used in selecting the appropriate protection methods:

- Wherever possible, passive protection methods are given preference over active systems; that is, passive fire rated or non-combustible construction, barriers and spatial separation are first reviewed for the ability to achieve the required level of protection before active suppression systems are considered
- Non-combustible materials are used wherever feasible to minimize the hazard
- Active suppression systems are provided where required by the referenced documents
- Wherever possible, wet pipe sprinklers are used, dry pipe for potentially freezing areas, and deluge for high challenge systems
- Alarm and detection systems are provided where required by the referenced documents; type of detection is based on the type of fire expected, and the need for sensitivity or fast response, to provide for rapid manual response or effective process shutdown to minimize damage
- Automatic Smoke Detection: Computer equipment rooms or areas that exceed the $250,000 limit established by DOE require smoke detection
- Automatic Sprinkler Protection: Computer equipment rooms or areas that exceed the $1,000,000 limit require sprinkler protection

- Fire Barriers: Where building Maximum Possible Fire Loss (MPFL) values exceed $50 M, buildings are subdivided into fire areas with an MPFL value less than $50 M; where this approach is not operationally feasible, redundant fire protection systems are provided
- For facilities where DOE orders or referenced code requirements cannot be met, the need to develop equivalent protection is identified

The FHA for Building 912, which was performed by outside consultants while the Prototype ERL was constructed in the NEBA portion of the building, indicated sprinklers would be required for some Prototype ERL rooms and some proposed Prototype ERL equipment.[16] The sprinkler feed would be via a 4-inch feed already in the NEBA Building 912 area.

The FHA consultant defined the approximate total value of the equipment in the ERL area as $5 M since the experiment uses a high value klystron gun that operates at 20 amps and 100,000 volts. Associated with the klystron gun is a power supply that is also high value. In 2007 before the Prototype ERL was completed, the FHA consultant indicated that parts of the Prototype ERL were to be protected with smoke detection; and a high-sensitivity smoke detection system was provided at the main ceiling above the Prototype ERL accelerator enclosure. The consultant indicated the control room area just outside the NEBA Building needed to be protected with automatic sprinklers and smoke detection.

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[16] R. Wheeler, Hughes Associates, Inc., 3610 Commerce Drive, Suite 817, Baltimore, MD 21227-1652

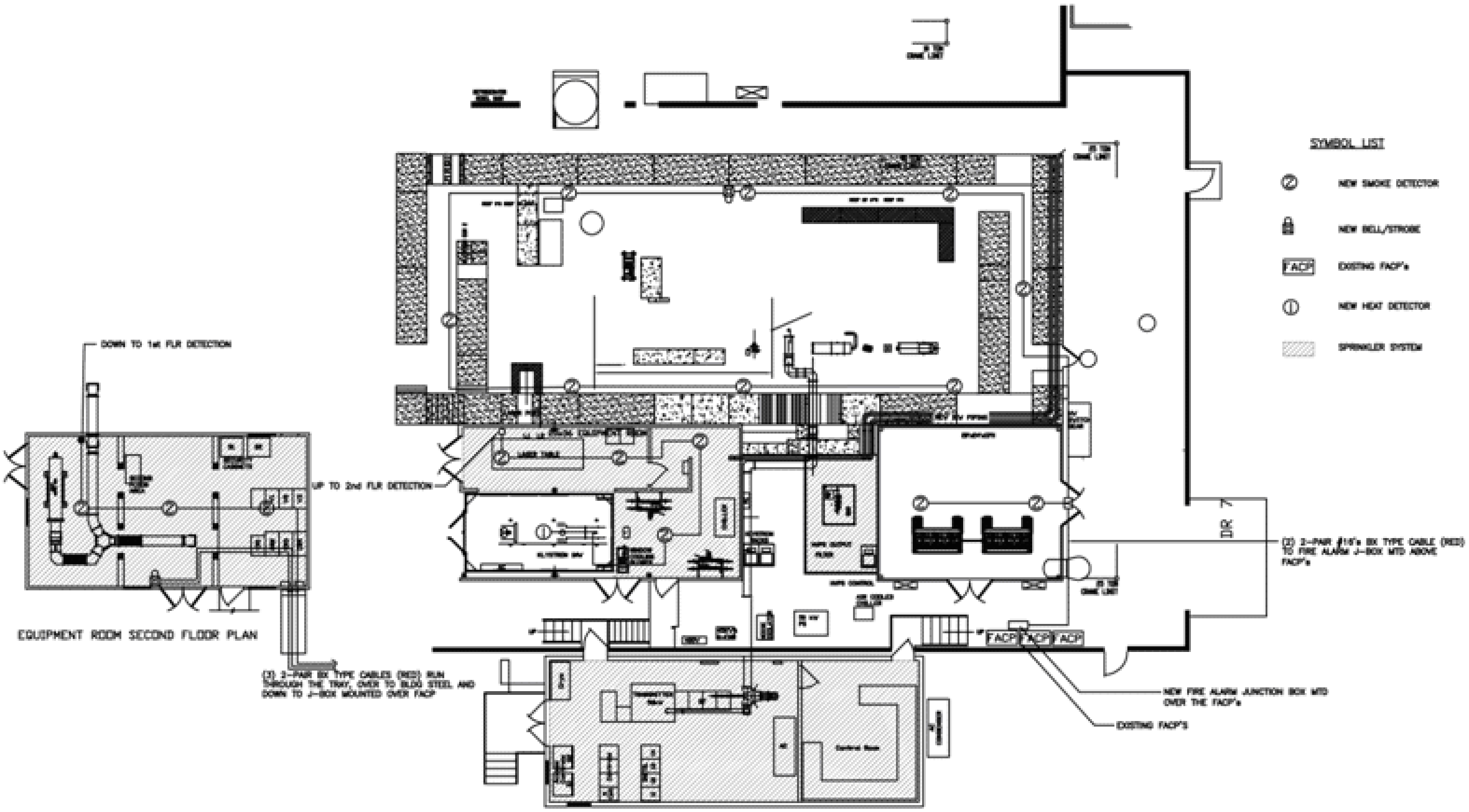
Based on the FHA by the consultant and on a room-by-room analyses of Prototype ERL with the BNL Fire Protection Engineer and Prototype ERL project management, the following fire detection and protection features for Prototype ERL were implemented:

- The smoke detectors in the high-voltage power-supply-room interlock power off if smoke is detected
- Transformers have over-current protection
- The two large 100 kV transformers just outside the power-supply room are filled with Envirotemp FR3 Fluid (fire-point is 360 ^{o}C)
- A total of 800 gallons of seed-based oil is used and it is biodegradable
- Sprinklers are placed above the two large 100 kV transformers
- The high-sensitivity smoke detector near the ceiling of NEBA Building 912 interlocks the power to the 100 kV transformers off upon detecting smoke
- The first-floor ERL chiller area room has sprinklers and smoke detectors turn off power to the 100 kV transformers
- The first-floor laser room has sprinklers and smoke detectors that transmit alarm signals
- The first-floor klystron room has smoke detectors turn off power turn off power to the 100 kV transformers
- The second floor of high-rise has sprinklers and smoke detectors turn off power turn off power to the 100 kV transformers
- The pump room has smoke detectors that transmit alarm signals
- The Prototype ERL control room has sprinklers and smoke detectors
- The fire-alarm annunciation at Prototype ERL turns off power to the 100 kV transformers

- A procedure for ‘manual power turn-off in the event of a fire’, was written for the Prototype ERL area and trained on by the Collider-Accelerator Support Group
- A combustibles-control-plan was written for the accelerator ring enclosure and trained on by the Prototype ERL operators
- The accelerator ring enclosure has smoke detectors

A drawing showing the location of fire protection and fire detection devices is shown in Figure 3.14.1.a.

Figure 3.14.1.a Prototype ERL Fire Protection System



Shielding

The policy upon which Prototype ERL shielding was designed can be found in Appendix 3, C-AD Shielding Policy. By adhering to the principles of this policy, Prototype ERL workers will not receive a planned exposure in excess of 500 mrem per year, or a fault exposure greater than 20 mrem. Prior experience at C-AD has shown that maintaining this policy for shield design results in workers actually receiving 10% or less of the planned exposure. This is largely due to work planning, conservative shielding design calculations, an active ALARA program and the fact that shield blocks come in standard sizes and thicker than calculated thickness is used in practice.

The shielding is in accord with the design criteria in 10CFR835 dated June 8, 2007. In addition to meeting the design criteria, a comparison of the pre-June 8, 2007 10CFR835 quality factors and the new 10CFR835 radiation weighting factors for neutrons is shown in the table below. In Chapter 4 of this document, the analysis shows the total dose equivalent outside the shield is dominated by photons, with only a few % attributed to neutrons. A factor of 1.5 to 2 higher in neutron dose equivalent is calculated using the radiation weighting factor, while total calculated dose equivalent from the radiation field near the Prototype ERL remains the same.

Neutron Energy (MeV)	Weighting Factor, W_R	Quality Factor, Q
1	20.7	11
2	17.3	9.5
2.5	16	9
3	15	8.7
4	13.3	8.4
5	12	8
6	11	7.5
7	10.3	7

The general layouts of the important shields are shown in Figures 3.14.1b and 3.14.1c. Neutrons and photons are the predominant radiation outside the ring enclosure, and concrete is the predominant shield material. Bremsstrahlung radiation is the predominant ionizing-radiation-hazard associated with the klystron high-voltage tube, and the best shield for these lower energy photons is lead.

Penetrations and seams in the shielding will be studied during initial operations since these are the hardest features to predict accurately in terms of calculated radiation dose rates. Thus, the shielding in the layouts is “planned” as shown here. Based on measurements, anywhere unusual shielding features conspire to elevate radiation levels above the plan, then that shield will be improved.

Figure 3.14.1.b Prototype ERL Klystron Lead Shield Layout

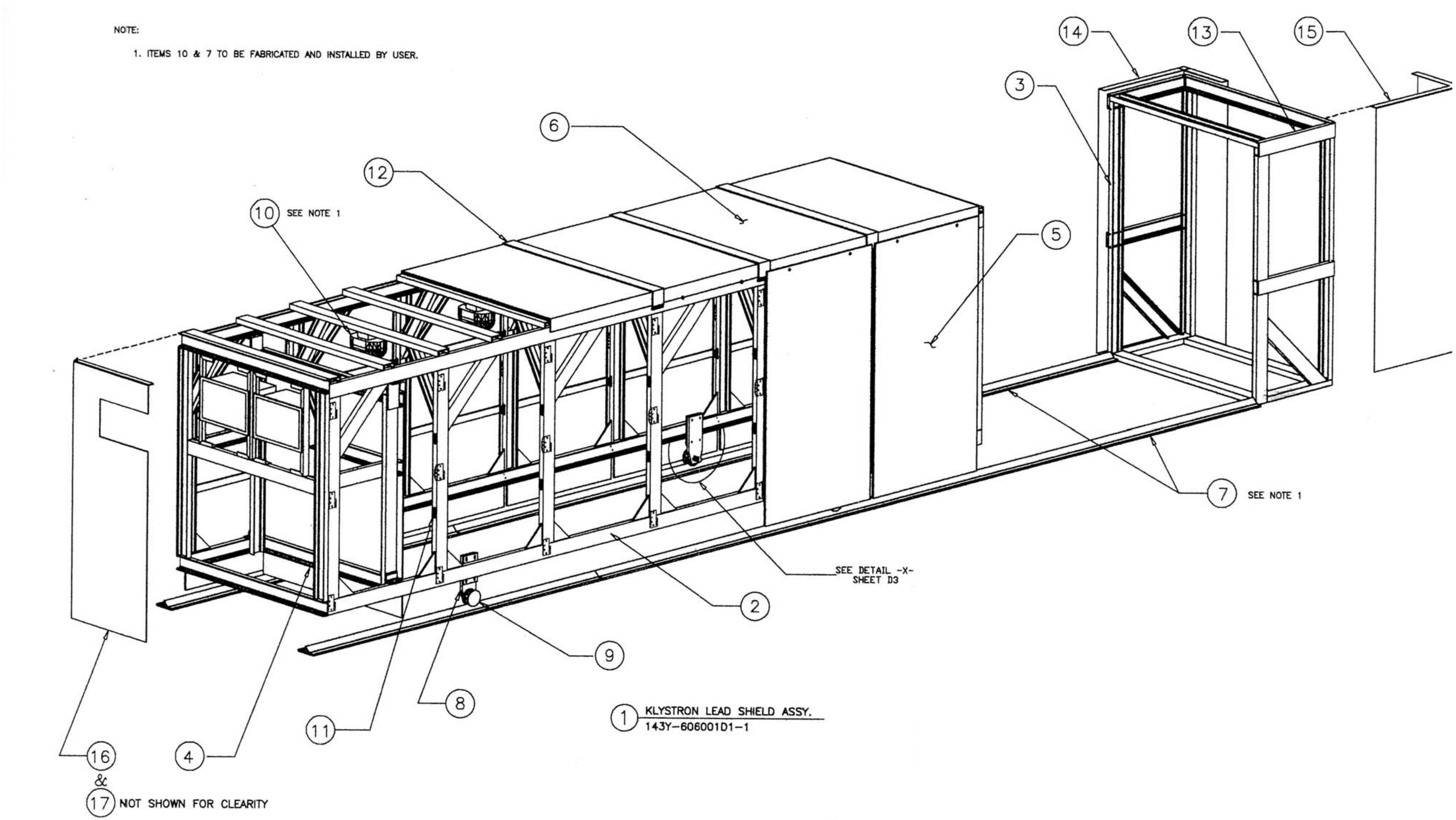
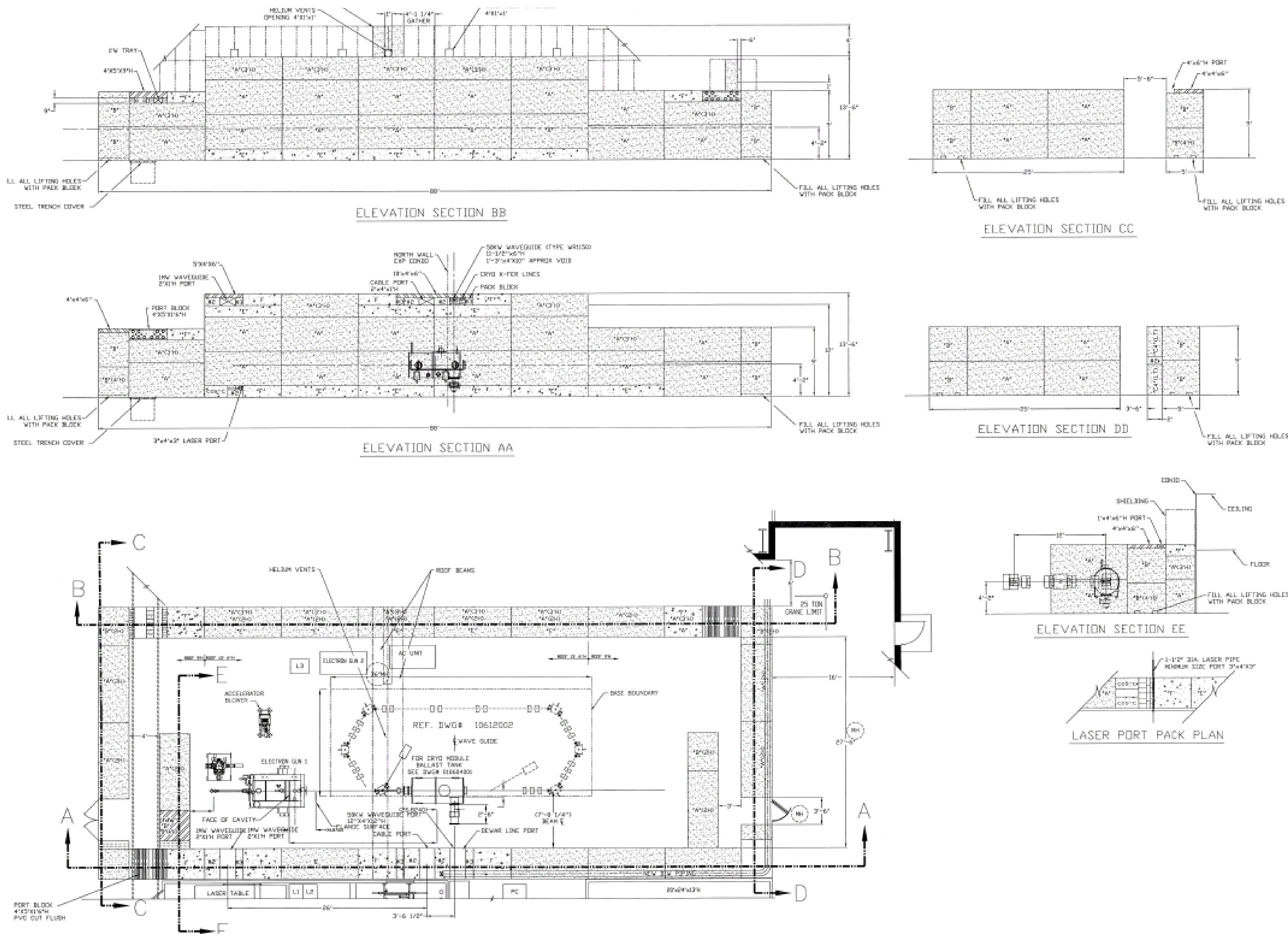


Figure 3.14.1.c Prototype ERL General Shield Layout



4. Safety Analysis

The level of detail included was correlated with the size, complexity, hazards, potential impacts and risks associated with Prototype ERL facility operation. The hazards analysis is comprehensive, and explored the full range of consequences each hazard could have on workers, the public, and the environment. It was based on sound assumptions so that effort would be focused on analysis of credible and realistic consequences. As allowed by DOE G 420.2-1[17], this SAD references a survey of the hazards present at the accelerator facility, including prompt radiation, radioactive materials, non-ionizing radiation, hazardous materials, and sources of energy. The hazard evaluation information in the SAD includes credible initiating events, the assumptions used in estimating the consequences, and controls required to reduce hazards and associated risk to acceptable levels. Identified controls were evaluated to determine if any were credited controls.

A credited control is one determined through hazard evaluation to be essential for safe operation directly related to the protection of personnel or the environment. The credited controls are a limited subset of the total controls employed for overall facility operation. Credited controls were assigned a higher degree of operational assurance than other controls. For example if a system, equipment or practice actively or passively protects workers and/or staff from a significant hazard, then it has formal administrative controls or limits for operation. These credited controls are treated specially and considered for incorporation in the ASE, appropriate procedures and/or quality assurance.

[17] Accelerator Facility Safety Implementation Guide for DOE O 420.2B, Safety Of Accelerator Facilities

Implicit in the above discussion is that analysis of hazards, consequences, and the types and reliability of controls, involved professional judgment. This judgment was based on sound technical and/or scientific principles using accepted methods for hazard analysis suitable for the types and magnitudes of hazards present.

4.1. Identification of Potentially Hazardous Conditions from Radiation Associated With Operation

At ERL, the primary electron beam is only present when the machine is operating. Before interacting at a particular location, the accelerated beam is essentially mono-energetic, consisting of only electrons. If the electrons stop in the accelerator equipment, beam stop or shielding, then electromagnetic cascades and Bremsstrahlung radiation can occur. For lower energy electrons, 25 MeV or less, Bremsstrahlung radiation contributes substantially to the energy loss by electrons in matter. Bremsstrahlung radiation is emitted by a decelerating charged particle or by a charged particle changing direction. Bremsstrahlung is German for braking radiation, and in particular, the term is used for photon radiation emitted by electron decelerations when electrons pass through the electric field of atomic nuclei. This produces photon radiation distributed over a wide range of energies.

If electrons are accelerated in a magnetic field, they can also produce photons and this is termed synchrotron radiation. Synchrotron radiation from this accelerator is produced when the electron beam circulates in the magnetic field of the ring. This synchrotron radiation is low energy and is attenuated by the shielding used for Bremsstrahlung.

When the machine is operating, the radiation outside the shielding is dominated by indirectly ionizing radiation such as photons and neutrons that penetrate the shielding. Neutrons are produced from the higher-energy Bremsstrahlung photons that interact with nuclei that make up the concrete shield. Because these are lower-energy Bremsstrahlung photons, at least in terms of causing nuclear reactions, the dominant neutron-producing mechanism is the giant nuclear resonance. Among the best-known example is the giant electric dipole (E1) resonance, which is concentrated in the energy region of 10 to 30 MeV for most, if not all, nuclei. In the E1 resonance, all protons and all neutrons in the nucleus oscillate with opposite phase, which produces a time-varying electric dipole moment, which acts as an effective antenna for absorbing or radiating gamma rays. The E1 resonance is the best known of the nuclear giant resonances. It is the dominant feature in reactions initiated by gamma rays. The absorption of a gamma ray induces the giant E1 oscillation, which breaks up, in this case, by emitting neutrons. This resonance is also the dominant feature in the reverse process, in which gamma rays are produced by proton and neutron bombardments of nuclei.[18]

The neutron spectrum from the E1 resonance process is often compared to a fission spectrum and is well described by a Maxwellian distribution. Shielding is relatively straightforward. The neutron-dose-equivalent tenth-value-layer for ordinary and heavy concrete is about 100 g cm^{-2} for this neutron spectrum.[19]

[18] http://www.answers.com/topic/giant-nuclear-resonance?cat=technology, January 2008.
[19] NCRP 144, Radiation Protection for Particle Accelerator Facilities, December 2003.

Neutrons can induce radioactivity in the Prototype ERL machine components, cooling water and nearby equipment. This neutron activation is expected to be insignificant at ERL because the electron energies into the beam dump are well below most activation thresholds. Residual radiation from the dump will be verified by radiation surveys near the beam dump after the machine is turned off, and by cooling water sampling and analysis. Radiation controls are in place as required during entry into the Prototype ERL following machine shutdown for inspection, maintenance, modification or repair activities. Because of the insignificant activation at ERL no contamination issues are expected.

The principal radiation hazards at Prototype ERL derive from the primary electron beam flux and duty-cycle of the machine. Listed in order of relative importance to health, these hazards include:

- Potential inadvertent exposure of workers to primary electron beam or RF induced x-rays from the electron gun or 5-cell accelerating cavities

  NOTE: The access controls system and the enclosed beam pipe prevent exposure of personnel to this beam. The probability of unsafe failure of the access controls system that would allow an overexposure from primary beam or Bremsstrahlung is so low[20] that this hazard is not credible and further analysis is not performed.

- Exposure to photon and neutron radiation near labyrinths and penetrations
- Exposure to photon and neutron radiation that penetrates through the shielding
- Exposure to skyshine radiation

[20] D. Beavis, Failures in the PLC Based Radiation Safety Systems, October 31, 2000; D. Beavis, Frequency of Interlock Testing, November 6, 2000; D. Beavis, Estimation of Time to Loss of Protection-The D-Downstream Gate, November 13, 2000.

NOTE: Escaping neutrons and gammas through thin parts of the shield or roof causes skyshine radiation; that is, the escaping radiation interacts with atoms in the air column above the accelerator and some of the resulting lower-energy radiation is scattered downward from these interactions. Skyshine radiation may extend many tens of meters from this accelerator. The Prototype ERL roof shields are inaccessible, via administrative access controls, during operations. The concern here are the dose rates from skyshine in the Prototype ERL Control Room, B966 and B940 due to the expected occupancy of these areas relative to other areas surrounding ERL. However, this source is expected to be insignificant during routine beam operations. This will be confirmed during routine radiation surveys and by environmental thermo-luminescent dosimeters (TLDs) placed around the facility.

- Exposure to activated air
- Exposure to potential residual radiation induced in machine components
- Exposure to or inadvertent release of activated cooling water to the environment

The ERL is an experimental machine that may undergo changes in operations as more is learned about its operating characteristics. If any of these changes involve a potential change in the radiation hazards, appropriate work planning and safety-committee reviews will take place to ensure that the BNL Radiological Control Manual requirements are met and ASE limits continue to be satisfied. If the ASE limits need to be revised to allow more flexibility in research/operations, the proposed ASE changes will be submitted to DOE for approval before the changes occur.

Estimates of the expected dose rates from Prototype ERL operations are described below. During commissioning, radiation surveys will be conducted to validate these estimates. The expectation is that actual dose rates will be below these computed does rates. If necessary, the shielding will be appropriately modified to ensure that routine and faulted doses and dose rates will be acceptable for full power operation of Prototype ERL.

Table 4.1 Parameters of the Prototype ERL in Building 912

	High charge mode	Low charge mode
Injection energy, MeV	3.5	3.5
Maximum beam energy, MeV	25	25
Average beam current, mA	100-200	10-200
Bunch rep-rate, MHz	9.4	9.4-700
Charge per bunch, nC	10 or more	~0.3 -1
Efficiency of current recovery	>99.95%	>99.95%

The proposed ASE limitations for the Prototype ERL are summarized below. It is noted that rated power sources for Prototype ERL, 1 MW for the gun and 50 kW for the 5-cell cavity, were increased 20% to estimate dose and dose rates. Prototype ERL power sources are not designed to produce this increased power; rather, the shielding was analyzed at this increased power level. Thus, a safety margin of 1.2 has been included in the dose and dose rate calculations in this SAD:

- Electron energy limit of 3.5 MeV for the superconducting RF gun
- The power source of the superconducting gun is limited to delivering 1.2 MW of power to the gun
- Electron energy limit of 25 MeV for the ERL ring

- Electron beam power shall not exceed the equivalent of 10 MW of instantaneous power for the electron beam in the Prototype ERL ring
- The power source for the five-cell cavity will be limited to delivering a maximum of 60 kW of power to the cavity
- A beam power of 1.2 MW for electron beam striking the beam dump

4.1.1. Unshielded Source Radiation Levels

Based on average continuous beam current of 200 mA, the average beam power is 0.7 MW at 3.5 MeV and 5 MW at 25 MeV. For the purpose of setting limits in the ASE, 1.2 MW at 3.5 MeV and 10 MW at 25 MeV were chosen as the maximum beam powers.

Continuous beam loss in the electron ring is limited via the physics of the Prototype ERL. If beam in the ring is totally intercepted, continuous beam loss in the ring vanishes since no energy is recovered to accelerate the next pulse in the CW train of pulses coming from the electron gun. This self-limiting effect is one of the peculiarities of an Prototype ERL ring. The maximum continuous beam loss is limited by the power that can be restored by the 5-cell cavity power supply, which is 50 kW. As noted previously, for dose and dose rates calculations, a factor of 1.2 or 60 kW is assumed to be the restoring power.

On the way to the dump, it is not expected that the entire 3.5 MeV beam at average current can be lost at any single point for an extended period of time. In radiation protection it is a conservative practice to assume that all electron beams produce thick-target Bremsstrahlung in high-Z material, regardless of the actual thickness or type of target. Thick target curves (see figure that follows)[21] for Bremsstrahlung radiation from NCRP 144 Figure 3.5 show that a 3.5 MeV beam at 1.2 MW can produce instantaneous absorbed dose rates of 5×10^7 rad/h at 1 meter in the forward direction and 8×10^6 rad/h at 1 meter in the transverse direction. The 3.5 MeV beam has insufficient energy to cause a neutron dose contribution via the photon-giant-nuclear-resonance process. [22]

Routine loss of a small fraction of the 3.5 MeV beam is expected. In normal operations the losses of the 3.5 MeV beam will be dominated by loss at the collimator. One micro-amp of beam is anticipated to be routinely lost on the collimator. One micro-amp continuous 3.5 MeV beam loss, which is a beam power of 0.0035 kW, equates to a forward absorbed dose rate of 140 rad/h and a transverse absorbed dose rate of 28 rad/h at 1 meter with no shielding. The collimator is located in the transport between the gun and the first chicane.

The 3.5 MeV beam is not intended to be transported into the 25 MeV transport ring after the first bend after the superconducting RF cavity. For radiation safety purposes, interlocks prevent the transport of the 3.5 MeV beam past this magnet.

The electron gun beam power will eventually be transported to the beam dump. From Table 4.1, the average beam current is 200 milliamps. Two-hundred milliamps of continuous 3.5 MeV beam loss on the dump, which is a beam power of 700 kW, equates to a forward absorbed

[21] NCRP Report No. 144, Radiation Protection for Particle Accelerator Facilities, Figure 3.5
[22] Ibid, Figure 3.12

dose rate of $2.8x10^7$ rad/h and a transverse absorbed dose rate of $5.6x10^6$ rad/h at 1 meter with no shielding.

The high energy electron beam, 25 MeV, is separated from the low energy 3.5 MeV beam in the chicanes before and after the SRF cavity. Conservatively assuming a 60 kW maximum sustainable loss, which is the limit of the SRF power supply, NCRP 144 Figure 3.5 shows Bremsstrahlung dose rates of $4x10^7$ rad/h in the forward direction at 1 meter with no shielding, and $5x10^5$ rad/h in the transverse direction. Since this energy Bremsstrahlung also produces giant resonance neutrons, the 25 MeV beam generates the highest neutron yield.

Swanson[23] (see figure that follows) has illustrated the broad features of the radiation field due to the unshielded initial interactions of electrons. The figure shows the radiation dose is heavily dominated by the Bremsstrahlung contribution. However, this figure is useful for making crude estimates of the resultant neutron radiation field. For a 60 kW continuous loss of 25 MeV electron beam, neutron dose equivalents range between $6x10^3$ and $1x10^5$ rem/h at 1 meter, which are several orders of magnitude less than the dose equivalent from Bremsstrahlung. At C-AD, a value of 430 rem/kW-h at 1 meter was used in the RSC Chair's analysis for electron energy of 25 MeV (i.e., $3x10^4$ rem/h at 60 kW).[24]

[23] W. P. Swanson, Radiological Safety Aspects Of The Operation Of Electron Linear Accelerators, Technical Report No. 188, International Atomic Energy Agency (IAEA), Vienna, 1979. Adapted in Radiation Physics For Personnel And Environmental Protection, Fermilab Report Tm-1834, Revision 7, April 2004, J. Donald Cossairt, Fermi National Accelerator Laboratory.

[24] D. Beavis, Simple Estimate of ERL Radiation, August 1, 2006.

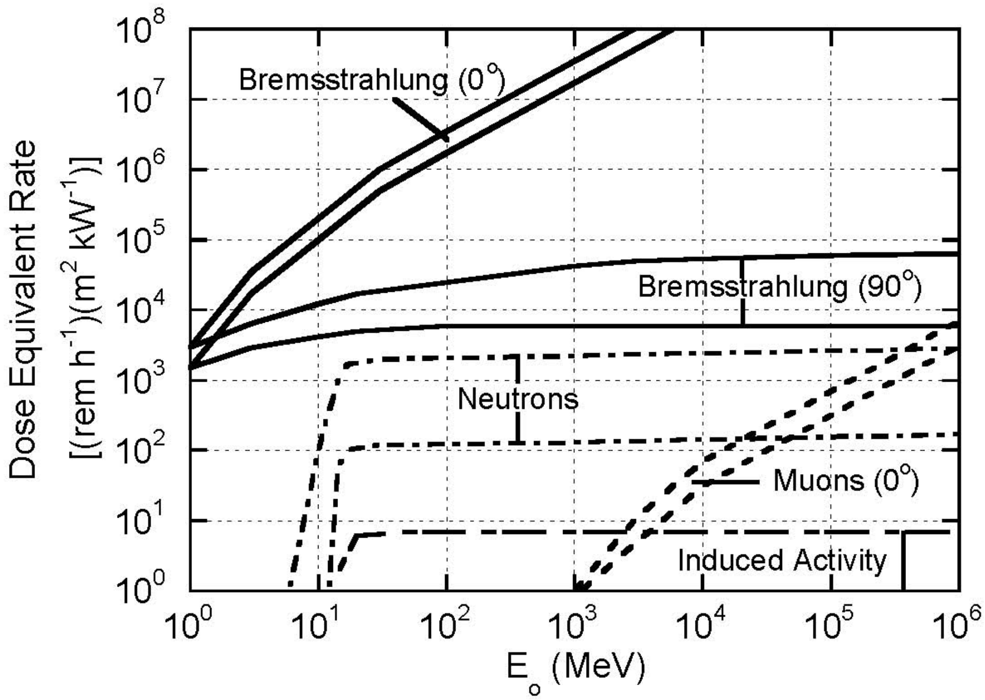


Fig. 3.10 Dose-equivalent rates per unit primary beam power at one meter produced by various types of "secondary" radiations from a high-Z target as a function of primary beam energy, if no shielding were present (qualitative). The width of the bands suggests the degree of variation found, depending on such factors as target material and thickness. The angles at which the various processes are most important are indicated. [Adapted from (Sw79a).]

The unshielded dose rate values represent a starting point for appropriately shielding the facility in order to adhere to the C-AD Shielding Policy. Section 4.1.2, which is the next section, contains detailed results of calculations that were performed for the shielded facility.

4.1.2. Maximum Credible Dose Rates on Outside Surface of 48-Inch Concrete Shield

Beam loss in the ring is limited for machine protection by beam current transformers used in a differential mode, and is anticipated being low because high loss would cause major equipment damage, quickly terminating operation of the accelerator. On the other hand, for this analysis the machine protection system is not credited in reducing dose from a beam loss event.

The maximum sustained beam loss is 1.2 MW for 3.5 MeV injection electrons and 60 kW in the 25 MeV ring. Credible routine losses are expected to be 1 W at beam injection and 50 W for the 25 MeV beam. Additional heavy concrete or iron shielding for the electron ring in the cave is present to reduce the Bremsstrahlung dose rate in the forward direction. This added shielding reduces the 0-degree Bremsstrahlung dose rates by a factor of at least 0.005. Including this added shielding, the following estimates for gamma and neutron dose rates at the outside surface of the Prototype ERL cave shielding are shown in Table 4.1.2.a.[25,26] Details of the calculations are given in Appendix 1.

[25] D. Beavis, Simple Estimate of ERL Radiation, August 1, 2006
[26] D. Beavis, The Effectiveness of a Two-Foot Thick Inner Heavy Concrete Wall, December 11, 2006

Table 4.1.2.a Dose Outside of Prototype ERL Cave for 3.5 and 25 MeV Electrons

Condition	Instantaneous dose rate from maximum beam loss[a]	Dose rate from sustainable loss[b]	Dose from sustainable loss assuming interlock occurs[d]
3.5MeV@ 0 degrees, γ	88,000 mrad/h	0.073 mrad/h	0.0002 mrad
3.5MeV@ 90 degrees, γ	18,000 mrad/h	0.015 mrad/h	0.00004 mrad
25 MeV@ 0 degrees, γ	65,000 mrad/h[c]	4000 mrad/h[c]	10 mrad[c]
25 MeV @ 90 degrees, γ	13,000 mrad/h	800 mrad/h	2.0 mrad
25 MeV neutrons	120 mrem/h	6.0 mrem/h	0.015 mrem

[a] The maximum instantaneous beam loss is 1.2 MW at 3.5 MeV and 10 MW at 25 MeV, a loss which would terminate after a small fraction of a second.
[b] The sustainable loss is 1 W for 3.5 MeV and 60 kW for 25 MeV electrons is assumed.
[c] The forward direction gamma dose rates have been reduced by a factor of 0.005 by the addition of 2-feet of heavy concrete in the electron ring.
[d] As with all C-AD interlocking area-dose-rate monitors (named ‘Chipmunks’), a 9-second delay from sensing the trip point dose rate to stopping of beam is conservatively assumed in SAD analyses.

Routine surveys during commissioning will ensure that radiation area postings reflect the actual dose rates during operations.

The electron gun and the 5-cell accelerating cavity will generate x-rays from field emission of wall-surface electrons. They are assumed to generate x-ray dose rates similar to the RHIC RF cavities. A conservative dose rate of 2000 rad/h at 1 meter is assumed for the maximum sustainable loss during conditioning of the cavity and 80 rad/h at 1 meter is assumed for routine losses. Comparison of this source with the dose rates from the routine electron beam loss shows that the x-ray dose rates at the outside surface of the Prototype ERL cave shielding are insignificant.

The Monte Carlo Neutron Photon Transport Computer Code (MCNPX) was run to estimate the dose rates from skyshine in normally occupied areas during ERL operations. The results are summarized below for the assumed maximum sustainable loss of 60 kW, and for a more realistic but conservative loss of 50 W assuming that Chipmunks interlock the beam at a set point determined by the RSC. It is noted that Prototype ERL will be run only about 25% of a year. Using this occupancy with the expected sustainable loss of 50 W, the annual dose to an individual in the Prototype ERL control room will be 41 mrem.

Table 4.1.2.b Skyshine Dose Rate Estimates From 25 MeV Beam Loss[27]

Occupied Location	Maximum sustainable loss (60 kW of 25 MeV electron beam)	Conservative sustainable loss (50 W of 25 MeV electron beam)	Maximum dose with 60 kW loss assuming Chipmunk Trips Beam
ERL Control Room	98 mrem/h	0.082 mrem/h	0.25 mrem
Building 966	26 mrem/h	0.022 mrem/h	0.07 mrem
Building 940	4.0 mrem/h	0.0033 mrem/h	0.01 mrem

The Klystron room shielding was based on the operation of a similar Klystron at Los Alamos, which had a 1/8 inch lead "garage" over it. The Prototype ERL Klystron operates at an upper voltage of ~92 kV. For the ~200 kV upper energy limit of the x-rays, the 1/8 inch of lead was computed[28] to be equivalent to 1-inch of steel at operating voltage and ~2.1 inches of steel at 150 kV. Based on this calculation and radiation measurements made at the manufacturer's facility, the Klystron room is a steel box with a wall thickness of 2 inches of steel. There are penetrations in the back wall for utilities and the wave guide. These penetrations are shadowed by steel and lead to prevent x-rays from directly shining out.

Dose estimates for the penetrations use a combination of simple source terms and estimates of the attenuation of the radiation as it propagates through the opening.[29] The estimates are intended to be order of magnitude estimates. Conservative assumptions are usually used so that the estimates represent upper limits for the potential dose rates. The low-intensity fault studies for the RF-gun, five-cell cavity, and transport of the low energy and high energy

[27] Email from K. Yip to R. Karol dated January 29, 2008, Skyshine
[28] MicroShield Version 7.02, Grove Software Incorporated
[29] D. Beavis, Dose Rate Estimates for ERL Penetrations, March 26, 2008.

electron beams will be used to verify the source terms and radiation transport through the shielding and penetrations.

There are approximately 20 penetrations through the Prototype ERL external shielding. Two of the major penetrations are used for personnel and equipment access. Several of the penetrations are buss blocks containing several dozen small penetrations for access of utilities. Other penetrations are intended for electrical cables, cryogens, gas exhaust, laser beam, etc.

The ERL enclosure has side walls composed of between four and eight feet of light concrete. The thin sections of wall are shadowed from the potential sources with inner shield walls located appropriately. The entire facility has a single layer of light concrete roof beams four feet thick, except for a transition region where the roof is two layers of roof beams. This transition region is where the 13 foot ceiling height in the center is reduced to 9 feet at both ends.

The radiation sources are predominately x-rays and gamma rays. The 25 MeV electron beam is capable of generating neutrons. Only in conditions where substantial high-Z shielding materials have been used or where it takes many bounces for radiation to get through a penetration is it possible for the neutron dose rates to dominate the x-ray dose rates.

The shielding was evaluated for two types of exposures, normal and fault conditions. Dose rates during fault conditions are typically many orders of magnitude larger than that of normal operating conditions. The areas around the penetrations are typically not occupied and they are posted for localized elevated dose rates. The main focus of the penetration analysis is the issue of dose to personnel during a faulted beam condition, as opposed to dose from normal operations.

During operations, all areas near the Prototype ERL shielding are posted at least as a Radiation Area. Large dose rates caused by fault conditions are detected and controlled by area radiation monitors (Chipmunks) distributed around the area as defined by the RSC. These devices are coupled with the interlock system and terminate the radiation in 1 to 9 seconds depending on the level of radiation at the detector. A delay of 9 seconds was assumed for the estimate of dose from fault conditions.

The four sources of radiation in the area are the injector, beam losses of the 3.5 MeV electron beam, the five-cell cavity, and beam losses of the 25 MeV electron beam. The source terms used are conservative. As already noted, the fault studies at low intensity will provide a check on the source terms and the effectiveness of the installed shielding.

The injector and the five-cell cavity can generate copious x-rays. No modeling has been conducted for the injector and the five-cell cavity in terms of the x-ray generation, but experience from other similar systems at C-AD can be used for guidance. The conditioning of these RF cavities will cause the largest x-ray generation. The superconducting five-cell cavity is expected to be able to absorb 100 to 1000 watts from field emission electrons crashing into the walls of the cavity before boiling too much helium and becoming normal. The voltage difference that field emission electrons cross is typically less than the gradient of a single cavity, 5 MV. Only a few electrons accelerate across several cavities. It is assumed that all the electrons are at 3.5 MeV with a maximum conditioning loss of 250 W. It is expected that the routine loss is less than 10

W for the five cell cavities. It was assumed that the injector has this same characteristic. Previous methods[30] are used to estimate the 90-degree radiation, using thick target formulas. The calculated unshielded dose rates for conditioning are 2000 rem/h at 1 meter, and for normal operations, 80 rem/h at 1 meter. Thus, the shielding used to protect against normal electron beam losses is adequate to protect against this source too.

The dose from a 25 MeV electron beam loss in the near zero degree direction has been estimated to be 10,800 rad/hr at 3 meters with 2 feet of heavy concrete between the source and the point of interest with a 60 kW loss[31]. This value was used in the calculations for locations where an inner shield wall acts as a shadow for the 25 MeV beam losses in the ring.

The maximum sustainable beam loss that the 5 cell cavity can support is 60 kW, which is limited by the RF power supply. According to the machine designers, the realistic maximum local loss that can occur is between 10 and 100 W before the machine is damaged and shuts down. The ERL has machine protection devices to limit losses in order to avoid equipment damage. Thus, the 60 kW loss assumed for shielding calculations (Appendix 1) is considered conservative. Routine losses are expected to be less than 10 W.

The 3.5 MeV beam has a power limit of 1.2 MW. This power can be deposited in the water cooled beam dump, which has local shielding. Again it is not expected that the machine can survive a large beam loss at any location, except at the beam dump. The beam dump is shielded sufficiently and was not considered for the penetration evaluations.

[30] D. Beavis, "Simple Estimates of ERL Radiation", August 9, 2008.
[31] D. Beavis, "The Effectiveness of a Two-Foot Thick Inner Concrete Wall", December 11, 2006, Figure 1.

An arbitrary 1 kW of a 3.5 MeV electron beam was assumed for the penetration analysis. A routine loss of 10 W or less is expected. Any routine loss higher than this, as observed during daily radiation surveys, will be reviewed by the RSC for the possible addition of local shielding.

The following table (Table 4.1.2.c) summarizes the calculations in Appendix 1 for each penetration for gamma rays and neutrons. The maximum neutrons can come from a different source location than the gamma rays. In all cases the maximum gamma dose rates are from the 25 MeV electron beam losses.

Table 4.1.2.c Estimated Maximum Dose Rates and Fault Dose to Worker Near Penetrations

Penetration	Maximum Gamma Dose Rate (rem/h)	Maximum Neutron Dose Rate (rem/h)	Maximum Dose with Interlock (mrem)[8]
Laser port	2.5	0.024	6.3
1 MW Waveguide	50	0.48	130
Cryo Ports (5)	10 [1]	2.4 [1]	31
North Gate	0.31	2.2	6.3
North Labyrinth Buss Block	4.8 [2]	0.12	12
South Gate	59 [3]	0.19	150
Port in South Labyrinth (2)	72 [4]	0.72	180
West Trench	7.2	0.12	18
East Trench	2.4	1.9	11
South labyrinth buss block	0.12	0.36	1.2
ODH Vent	12 [5]	4.8 [5]	4.2
Lifting Fixture holes (4)	1.7 [6]	0.010 [6]	4.3
50 kW waveguide	34 [7]	1.2 [7]	88

[1] Assumes that steel has been used to reduce the gamma rays by a factor of 10.
[2] This is directly outside the buss block. This may be in a fenced area.
[3] A shield block in the ring center would substantially reduce this dose rate, if desired.
[4] At port exit which may be in a fenced area. Port may be packed in the future. This value is for the port with the highest dose rate of the two ports.
[5] This is on the roof and is not allowed to have personnel access during operations.
[6] Evaluated at the edge of the shielding and not on the roof.
[7] The penetrations for the cables ports, water pipes and the 50 kW waveguide are computed in a separate note[32]. The dose rates presented here are at a height of 12 feet above the floor.
[8] Barriers are used to prevent access to penetrations greater than 20 mrem fault dose. Shielding will be added and barriers removed based on fault studies in order to reduce the fault dose below 20 mrem.

All the dose rates in the Table 4.1.1.c are sufficiently low such that with appropriately placed Chipmunk monitors to terminate the beam on large beam losses, the exposure to personnel is less than 10 mrem from a fault. Where fault dose rate exceeds 50 rem/h at a penetration opening, dual failsafe Chipmunks must be used. However, several of the larger dose rates can be further reduced and fault studies will allow evaluation of the need for added shielding by the RSC.

[32]D. Beavis, "Estimate of the Radiation Exiting Penetrations for the ERL 50 kW Waveguide, Cable Buss Block, and Water Pipes", Dec. 6, 2006.

4.1.3. Maximum Credible Ozone Concentrations in the Prototype ERL Cave

Toxic gasses produced by ionizing radiation shows that ozone is among the most toxic and could be produced in quantities that cause the room to exceed the ACGIH Threshold Limit Value (TLV) level of 0.1 ppm. The TLV is the concentration that most workers could be safely exposed to 8 hours per day, 5 days a week. The highest radiation doses to air are where the highest local concentration will be located. There are no locations in the Prototype ERL beam line where electrons traverse air so only the radiation energy imparted by the Bremsstrahlung is considered in this analysis. The calculation model for ozone production in Swanson was used.[33]

The highest power level in the Prototype ERL is the energy deposited in the beam dump. This is 1.2 MW of 3.5 MeV electrons. For an uncollimated Bremsstrahlung beam from an optimum high-Z target, the production rate of ozone, P in liters per minute, is:

$$P = 1.7 \times 10^{-4} L\Omega$$

Where: L = meters of air

Ω = kW of electron beam power, 1200 kW for the beam dump

The beam dump is to be enclosed in a 1-foot lead shield with at most ~6" of air that the Bremsstrahlung beam passes through before encountering shielding. The actual air passage is much less. Using these conservative assumptions yields an ozone production rate of 0.03 L/m.

[33] W. P. Swanson, Toxic Gas Production at Electron Linear Accelerators, SLAC-PUB-2470, February 1980.

As indicated by Swanson, the mean life of ozone in air at room temperature, T, is 50 minutes for a radiation environment. Any natural ventilation of the cave is conservatively ignored. The calculated saturated concentration of ozone, C_{sat}, is:

$$C_{sat} = PT/V$$

The 6 inch air volume around the dump is 12,400 in^3 (200 L) since the dump is 60 inches long x 19 inches diameter. C_{sat} for that air-gap between the dump and lead shield is $7.5x10^3$ ppm. Assuming exchange of the air in the gap occurs with cave air (V of 20,000 ft^3 or 570,000 L), then saturation concentration is reduced by a factor of 200/570000 or to a level of 3 ppm, well above the TLV limit.

Based upon this calculated result, the beam dump is to be enclosed in a tight structure maintained free of air by using an inert gas such as helium, or the air space between the dump and the lead shield will be ventilated outside the cave into B912 where the ozone will significantly dilute to safe levels. Ozone measurements will be made during ERL commissioning to determine the actual magnitude of the ozone problem and to optimize the solution.

The credible sustainable losses of the electron beam are 1 W for the 3.5 MeV electrons and 50 W for the 25 MeV electrons. The length of air until the uncollimated Bremsstrahlung beam reaches shielding is no greater than 4 meters. Assuming that the ozone produced by these losses are continuous and reach saturation in the ERL cave, the ozone concentration is 0.0003 ppm for the 3.5 MeV beam loss and 0.01 ppm for the 25 MeV beam loss. Thus there are no unsafe ozone hazards from routine electron beam losses.

4.2. Identification of Potentially Hazardous Conditions from Oxygen Deficiency

OSHA defines an oxygen deficient atmosphere in 29CFR1910.146 as atmospheres containing less than 19.5% oxygen by volume. Normal atmospheres contain ~21% oxygen. Clinically observed effects from oxygen deficient atmospheres do not begin until the concentration falls to ~17%. If a small number of workers are exposed to potential oxygen deficient atmospheres, it is cost effective to use conservative controls for protection. However, with large exposed populations it is necessary to better establish controls at an appropriate level. With too little control, the injury rate may be unacceptably high. With too much control, the ability to operate efficiently is diminished.

Controls address two types of exposures: one where a known oxygen deficiency exists, the other in which an oxygen deficiency does not exist but there is a potential for its occurrence. The latter type exposure in particular applies to Prototype ERL, although a known oxygen deficiency could exist, for example, in a confined space such as a trench in which sample results show <19.5% oxygen. Work planning would determine the controls needed to safely work in this space. Controls would include periodic atmospheric monitoring, self-contained breathing apparatus, ventilation and confined space permits. The premise for controlling a potential oxygen deficiency is that the risk to workers should be no greater than risks in a general industry setting.

If exposure to reduced oxygen from an accidental event is stopped early enough, effects are reversible or avoided altogether. If not, permanent central nervous system damage or death can result. Major effects hindering escape from the vicinity of an oxygen deficiency are disorientation and unconsciousness. For personnel actively working, unconsciousness occurs at ~13% oxygen. A person in the general area of a catastrophic release of an inert gas and not hurt by a pressure wave would be alerted to the escaping gas by the noise and, if a cryogenic gas, the cold and resulting vapor cloud. ODH training is used to alert personnel to leave the area. In this case, personnel are trained to know that they can out-walk the expanding inert-gas cloud and safely walk out the nearest ERL cave exit.

The controls for potential oxygen deficiency are focused on the workers in the general area of the potential release. The survival of individuals in the general area is highly probable because of the engineering and administrative controls, monitoring systems, and training.

For the highly unlikely scenario in which an individual is in contact or very near failed equipment at the time of failure, the affected individual would be exposed to several hazards. These would include the powerful mechanical forces that resulted in a release of gas or cryogenic liquid, a pressure vessel failure for example, and the oxygen deficiency condition. In those extreme conditions, a person would lose consciousness in seconds and probably not survive.

Training for workers includes the methods to become aware that a release of inert gas has occurred, escape methods and use of appropriate oxygen monitoring devices and escape packs.

In addition to training on use of oxygen monitors and escape packs, ODH information is given in the facility specific courses required of all employees and users.

The C-AD SAD has a detailed description of the graded approach used to determine the controls necessary for areas having a potential for oxygen deficiency. It is recognized that these simplified methods cannot directly and quantitatively address the effects of the inert gas concentration gradients during transient release of the gas. The approach is to use a prescribed, simplified analysis to determine how an individual can have reasonable assurance that they are protected from a gas release. It treats the problem in a global way, by assuming uniform instantaneous mixing of the gas in all available volume within the enclosure. For nitrogen, helium and lighter gases, used at ERL this is reasonable. As already noted, individuals near the location of any release have higher likelihoods of injury or death. Thus a combination of the BNL SBMS ODH methods coupled with engineering judgment, assumptions on worker training, evacuation procedures and monitoring equipment are utilized in determining the controls needed to ensure an acceptably safe workplace.

The BNL SBMS models are used to determine the ODH classification of a building. The SBMS is based on the Fermi ODH model. The Fermi Model is a prescribed method to determine the necessary level of hazard control for a building having the potential for oxygen deficiency. A graded approach is used to implement hazard controls as a function of the computed ODH fatality rate. The fatality rate is selected as the hazard index since death is the most important, non-reversible effect of exposure to oxygen deficiency. The average US industrial fatality rate at the time the method was developed (1984), $\sim 10^{-7}$/hr, was defined to be the fatality rate at which protective measures, other than training and postings are required.[34] Today, that rate is about $2x10^{-8}$/hr.

Areas of ERL which have potential ODH hazards have been evaluated as described above. A low oxygen concentration set point/alarm is 18%. Alarm set points below 19.5% are acceptable because these alarms warn of accidents and not of planned, routine working conditions. ODH sensors and alarms will be located on the walls within the accelerator enclosure at eye level, and within the helium recovery building. These areas are small enough such that alarms are visible and audible from any location within the rooms. The results of the ODH analyses for the affected areas of ERL are summarized in Table 4.2.[35]

Table 4.2 Potential ODH Areas at ERL

Building	Free Volume	Bounding Cryogenic Leak Location	Spill Rate (SCFM)	ODH Exhaust Fan Capacity (SCFM)
ERL Cave in B912	20,000 ft^3	Failure of 1-inch copper LN2 transfer line	3275	13,750
ERL Helium Recovery Building	9500 ft^3	Rupture of Kinney vacuum pump helium discharge line	1150	4850

The Prototype ERL Cave volume assumed for ODH analyses conservatively excludes the labyrinth volumes and accounts for the equipment in the cave. The Prototype ERL helium recovery building volume also accounts for the equipment in the room. The results of the ODH calculations show that both the cave and the helium recovery building are ODH 0 areas.

[34] T. Miller and P. Mazur, Oxygen Deficiency Hazards Associated with Liquefied Gas Systems: Derivation of a program of Controls, Am. Ind. Hyg. Assoc. J. 45(5):293-298(1984).
[35] BNL LESHC Meeting Minutes 06-06, May 18, 2006, Energy Recovery Linac in Building 912R. Karol, ERL ODH Calculations, January 8, 2008.

4.3. Identification of Potentially Hazardous Conditions from Electrical Energy

Chapter 3 describes the numerous electrical devices, magnets, power supplies, vacuum system, Klystron, RF systems, beam instrumentation and controls that are employed at Prototype ERL.

The sheer number of electrical devices and their conductors installed at accelerator and experimental facilities justifies recognizing electrical hazards as a major personnel hazard which requires detailed hazard controls. C-AD adheres to BNL SBMS subject area on Electrical Safety supplemented by the C-A-OPM 1.5 procedure series, order to mitigate electrical hazards. The hazards are described as follows:

AC Distribution

1. The primary AC distribution is at 13.8 kV. The feeds are underground to substations located at various sites. Transformers convert the 13.8 kV to 480 volts AC for subsequent distribution. Because of the very high hazard, the substations are fenced in with controlled access by the BNL Plant Engineering personnel. C-AD personnel do not normally have access to these areas.
2. Secondary distribution is 480 V, 3 phase, 60 Hertz, high resistance ground delta with remote sub-station ground-fault monitoring system. This is used directly in many pieces of equipment, motors, pumps, power supplies, etc. It is further transformed to 220/120 V, 3 phase for lights, utility outlets and all general needs. The hazard at 480 V is not only from a 480 V shock, but also from the possible arc formation at a short circuit. The short circuit currents are extremely high and an arc can create a shock wave and spray molten

copper and other materials. The procedures followed on 480 V circuits include training, LOTO or key lockout, circuit voltage testing, and the use of proper personnel protective equipment, the use of which is based on arc flash calculation.

High Voltage, Direct Current

1. Low Current - In many pieces of electronic equipment there are high voltage, low current, power supplies. While the current in some cases may present a direct shock hazard, in others it will be too low to cause a direct injury, but may lead to indirect injuries, such as, falls, bumps or other physical or electrical mishaps. ERL components are prominently marked for a high voltage hazard and may also be interlocked if a direct shock hazard exists. ERL equipment uses high voltage power supplies and each set-up is reviewed by the ASSRC before being energized.
2. High Current - In the range of 10-50 mA passing through the body significant physical harm may occur. The RF systems, as well as various pulsed magnets, kickers, and other devices, use potentially lethal power supplies. All such power supplies are properly marked; interlocks actuated on entry to the supply are hard wired to the power source; panel indicator lights show the power supply status; local-remote lockout switches are provided where more than one turn-on location is used. Shorting devices are provided, manual or automatic, especially on capacitor storage devices.

High Current, Low Voltage

Many devices use high currents, up to several thousand amperes, at relatively low voltages. In most cases the shock hazards are low but a short circuit on the lines, just as in the 480 V AC case, can lead to excessively high temperatures. Training, proper warnings, enclosing of conductors and interlock devices are used.

RF Voltages

RF voltages in the many kilovolt level are present in the accelerating system. Contact can result in shock and deep RF burns. The procedures as in the high voltage DC case are used.

4.4. Fire Hazards

The primary combustible loading at Prototype ERL consists of magnets, power and control cables, and beam diagnostic equipment. None of the materials is highly flammable, and with the possible exception of small amounts of control cable, all are expected to self-extinguish upon the de-energizing of electric power. Small amounts of flammable materials such as cleaning fluids may be routinely used in support of Prototype ERL maintenance. These materials will be purchased and controlled in accord with BNL's Chemical Management System, and stored in accord with SBMS Subject Area requirements.

Due to a system for diversion of radioactive liquid effluent to a hold-up pond, there are no environmental impacts due to release of contaminated water from the fire protection water system. Water sprayed on potentially radioactive equipment may become slightly contaminated but would enter the sanitary system and be monitored before release. There are no significant amounts of combustible activated materials in the Prototype ERL and no significant radioactive particles would be present in smoke. Thus, there is no significant environmental hazard from a fire at the Prototype ERL.

To mitigate Prototype ERL fire hazards the systems are designed to industry codes and standards, there is fusing, limits exist on flammable gas volumes, there is fire detection, smoke detection alarms, sprinklers, control of combustible loading, ventilation systems, safety committee reviews, training for emergencies, control of ignition sources, and enhanced work planning.

4.5. Industrial Hazards

Standard industrial hazards such as lasers, vacuum and pressure, magnetic fields, cryogens, chemicals, and mechanical hazards are controlled by following the appropriate requirements in the BNL SBMS Subject Area.

4.6. Hazard Controls

The purpose of this section is to briefly summarize the various system features and administrative programs that help to control hazards or minimize risk of various hazards. It is noted that there are no credible offsite consequences from any Prototype ERL operations. Only workers or the environment are exposed to potential hazards.

4.6.1. Radiation Hazard Controls

The significant hazard at Prototype ERL is ionizing radiation, and operations are planned to be within DOE dose guidelines. The Department uses a graded system of controls such as shields, fences or barriers, locked gates, interlocks and procedures to match access restrictions with potential radiation hazards that satisfies both the BNL and DOE requirements.

Although the Laboratory site is a limited access site, service personnel from off-site or BNL non-radiation workers may work near ERL or may traverse the complex. The BNL policy is to administratively restrict the dose to 25 mrem per year to such personnel. The C-AD adheres to this policy by using shielding, postings, radiation monitoring devices that prevent radiation levels from exceeding set points, radiation work permits, work planning and RS LOTO.

Shielding for Prototype ERL is also designed to permit access by appropriately trained personnel to areas adjacent to the accelerator cave even with credible inadvertent beam loss.

There are restrictions on access for specific Prototype ERL facility areas. Access into the machine area is prevented by dual interlocks when the machine is operational. This includes the operation of the electron beams, the RF-Gun and 5-cell cavity. Personnel access to the roof is administratively prohibited during operations. Personnel are not allowed in the 1 MW Klystron power supply room during operations. A substantial area between the adjacent experimental building and the Prototype ERL shielding on the west side is fenced and locked with personnel excluded during operations or with limited access.

4.6.1.1. Permanent Shielding and ALARA Dose

Shielding is used to reduce radiation levels in occupied areas to acceptable levels. The C-AD's shielding policy is given in Appendix 3, Shielding Policy. Potential access points to the Prototype ERL cave where personnel are prohibited during operations will be controlled by the Access Control System and the use of chicanes.

Shielding design analyses were performed for Prototype ERL, and ALARA was integrated into the overall facility design. Soon after beam is available, studies will be conducted at low power in order to verify the design and to optimize shielding, as needed, to help achieve an ALARA dose to personnel. Extensive radiation surveys of normal operations, as well as low-intensity simulated, credible beam faults, are conducted as required during commissioning, initial operations and for future, approved modifications. These surveys provide assurance and verification of the adequacy of the shielding and access controls. It is noted that the permanent shielding and access controls are configured to support the BNL Radiation Control Manual dose limit requirements, and are further enhanced to support the BNL Radiation Control Manual ALARA considerations.

The shield was planned with ALARA in mind such that, during normal operations, the dose rate on accessible outside surfaces of the shield is planned to be less than 0.25 mrem/h in areas under access control. Areas under access control are all designated Controlled Areas or radiological areas as defined in the BNL Radiation Control Manual. The design of 0.25 mrem/hr is a guideline based on the actual ALARA design objective of less than 500 mrem per year. That is, assuming 100% occupancy at the shield face, a 2000-hour per year residence time yields an acceptable ALARA design objective of 500 mrem. The 500 mrem per year ALARA design objective is one half the design objective stated in 10CFR835 § 835.1002 (b).

Since there are many ways to control access and residence time by area designation, training, signage and work planning and since there is a decrease of dose rate with distance from the shield face, significantly higher shield face dose rates are acceptable. Therefore, shields are evaluated in terms of the guideline of 0.25 mrem/h, and instances where higher values may be acceptable have barriers and postings to indicate where area designations play a major role in minimizing radiation exposures.

The permanent bulk shielding materials used at Prototype ERL are primarily materials used at all existing accelerator facilities. For example, concrete and iron provide protection for personnel outside the accelerator cave and Klystron room. In addition to the materials mentioned above, paraffin, borated paraffin, polyethylene, borated polyethylene and Pb may be used for local shielding and in special circumstances, along with appropriate fire safety and industrial hygiene controls. Shielding configuration is closely controlled and may not be changed without review and approval of the C-AD RSC.

4.6.1.2. Radiation Detection and Radiation Interlocks

At locations external and/or adjacent to the Prototype ERL cave where unlikely but possible beam loss may occur, the use of hard-wired, fail-safe interlocking radiation monitors are used. This technique is standard practice at DOE accelerator facilities to maintain radiological-area classification compliance by providing a robust and rapid beam inhibit if any monitor exceeds a preset interlock limit. These radiation monitors are part of the QA level A1 safety-significant access-control-system for personnel protection.

Interlocking radiation monitors at C-AD are calibrated annually. These radiation monitors have been dubbed Chipmunks. They are tissue-equivalent ionization chambers that measure dose equivalent rate, in mrem per hour, from pulsed, mixed-field neutron and gamma radiation. In the ionization chamber, total ionization from a single radiation interaction event is collected. From this ionization, the Chipmunk circuitry produces one pulse for every pico-Coulomb of charge. If the circuit is overdriven, then the circuit produces a continuous train of pulses. This feature prevents the Chipmunk from jamming at very high dose rates. The range of the Chipmunk is about 1 mrem/h to 100,000 mrem/h. Chipmunks that are used as area-radiation monitors for personnel protection are located in accessible areas of the Prototype ERL facility as determined by the C-AD RSC. Chipmunks interlock the electron beam should radiation levels exceed limits defined by the C-AD RSC. The operation of Chipmunks with interlocking capability is fail-safe. Loss of power results in beam off for interlocked Chipmunks, and/or an alarm in the Prototype ERL Control Room adjacent to Building 912, a control room that is continually manned during routine operations. Additionally, the Chipmunk uses a built-in keepalive radiation source to monitor for failures. Such a failure will trigger an alarm in the Prototype ERL Control Room and/or an interlock when appropriate.

The interlock system is hard-wired and uses relay logic or PLCs to activate or deactivate a device or a magnet power supply to prevent beam from entering the fault area when a fault condition is detected. These systems are monitored by an independent computer, and the fault condition is logged.

Fixed-location area-radiation monitors such as Chipmunks also provide real-time dose information in B912. This dose rate data is logged every few minutes and stored on computers. General locations are initially selected for the real-time monitors; exact locations are determined based on beam-loss tests conducted during the Prototype ERL commissioning phase and on subsequent radiation surveys during operation. Final area radiation monitoring instrument locations are approved by the C-AD RSC.

Additional area monitors may be used to assess the long-term integrated dose in areas accessible to the public and other individuals not wearing personnel dosimeters. TLDs identical to those worn by radiation workers are mounted in locations in accordance with the BNL Radiological Controls Division procedures for this purpose. The dose recorded by these TLDs is indicative of the exposure of a person spending full time at that location. Neutron dosimeters, if their use is indicated for this purpose, will be attached to phantoms to simulate use by personnel.

4.6.1.3. Control of Radioactive Materials and Sources

When the electron beam is turned off, the remaining radiation hazard comes from activated material and sources. Activation of materials is expected to be either non-existent or insignificant at Prototype ERL. Activated material may be a direct radiation hazard, and may have removable contamination. All known or potentially activated items will be treated as radioactive material and handled in accordance with BNL Radiation Control Manual requirements. Unlabeled radioactive material that is accessible to personnel is placed in appropriately posted radiological area. Unless permitted by procedure, suspect radioactive material is surveyed by a qualified Radiological Control Technician (RCT) before release and then controlled in accordance with the survey results. Known radioactive materials are appropriately labeled before removal from an area that is posted and controlled. Radioactive items with removable contamination on accessible surfaces are packaged before removal from posted radiological areas. Workers whose job assignment involves working with radioactive materials receive documented training as radiological workers. Sealed radioactive sources below BNL accountable-activity-limits are treated as radioactive material. Accountable sealed radioactive sources are controlled, labeled and handled in accordance with the BNL SBMS Subject Area and the C-AD OPM. Accountable sealed radioactive sources that are in regular use are inventoried and leak-tested every six months.

4.6.1.4. Portable Radiation Monitors

Portable radiation detection instruments are used by RCTs and, potentially, other trained and approved C-AD personnel, to measure the radiation fields in occupied areas during commissioning and periodically during normal operations. The measurements made by RCTs will be used to establish and confirm area radiological postings. Instruments used for this purpose will be appropriate for the type and energy of the expected radiation, and will be calibrated in accordance with BNL requirements.

Experience at the C-AD accelerators and experiments have shown that contamination is not a significant problem at our facilities. Prototype ERL contamination is not expected, however, routine contamination surveys are conducted to verify that contamination is not a problem. Instruments used to frisk personnel who are exiting posted areas that might contain removable contamination are used as appropriate.

4.6.1.5. Personnel Dosimetry

All radiation workers wear appropriate TLDs and self-reading dosimeters as required by the BNL Radiation Control Manual while working in areas posted for radiation hazards. Dosimeters are exchanged on a regular basis and processed by a DOELAP-accredited laboratory. Records of the doses recorded by these dosimeters are maintained, and these records are available to the monitored individuals.

4.6.1.6. Access Controls Systems

The radiation security system design for access controls at ERL is classified as QA level A1 according to the C-AD QA plan, but the Department allows certain components to have a lower classification because failure is to a safe state or critical parts are redundant. The Access Controls Group installs industrial grade components only. This Group labels parts that pass incoming tests as A1 or A2 and places labeled parts in controlled storage areas. The Group maintains documentation for these acceptance tests.

The basic design principles of the access control system are:

- Either the beam is disabled or the related security area is secured
- Only wires, switches, relays, PLCs and active fail-safe devices, such as chipmunks, are used in the critical circuits of the system
- The de-energized state of the relay is the interlock status; that is, the system is fail-safe
- Areas where radiation levels can be greater than 50 rem/h require redundancy in disabling the beam and in securing the radiation area
- If a beam fails to be disabled as required by the state of its related security area, the system has backup or reach-back

Very High Radiation Areas are those areas that enclose primary beam. Very High Radiation Area hardware requirements comply with the BNL Radiation Control Manual. The C-AD RSC requires:

- Locked gates with two independent interlock systems
- Fail safe and redundant radiation monitors or other sensing devices
- Indicators of status at the facility in the Prototype ERL control room
- Warning of status change
- Emergency stop devices within potential Very High Radiation Areas

The C-AD RSC reviews interlock systems for compliance with requirements in the BNL Radiation Control Manual, SBMS requirements and C-AD OPM procedures. A Representative of the BNL Radiological Controls Division is a member of the C-AD RSC. The C-AD RSC defines the design objectives of the security system and approves the logic diagrams for relay-based circuits and state tables for PLC-based circuits. Cognizant engineers sign-off on wiring diagrams and the C-AD Chief Electrical Engineer approves each diagram. The C-AD Access Controls Group maintains design documentation.

The Access Controls Group conducts a complete functional check of all security system components at an interval required by the BNL Radiological Control Manual. In the checkout, the Access Controls Group checks the status of each door-switch on a gate, and each crash switch in the circuit. They check the interlocks and the off conditions for all security-related power-supplies to magnets and magnets that may act as beam switches. They check every component in a security circuit. As they test, they fill-out, initial and date the security system test-sheets obtained from the C-AD OPM. Test records are maintained as required by the C-AD OPM.

4.6.2. Control and Use of Hazardous Materials

The BNL Subject Area on Working with Chemicals is designed to ensure that workers are informed about the chemical hazards in their workplace. The Subject Area is maintained to comply with OSHA and EPA regulations concerning hazardous chemical communications. The BNL Subject Area on Working with Chemicals includes provisions for policy, training, monitoring exposure limits, handling, storing, and labeling and equipment design, as they apply to hazardous materials. Inclusive in the hazardous material protection program will be: procurement, usage, storing, inventory, access to the hazardous materials, use of appropriate Personal Protective Equipment (PPE), as well as housekeeping and chemical hygiene inspections of C-AD facilities. All BNL general employees receive appropriate general Hazard Communication training. Standards for general hazardous materials communication are specified by the BNL SBMS. Training to these standards is provided, and the training program records are maintained on the Brookhaven Training Management System (BTMS). C-AD staff working in ERL areas with a potential for exposure to hazardous chemicals receive appropriate job-specific training at the time of initial assignment and whenever a new hazard is introduced into the work area. A comprehensive listing of all Materials Safety Data Sheets for the chemicals used at the BNL site is available on the BNL web;[36] a goal is to have all chemicals accounted for in the BNL Chemical Management System (CMS). The system of work controls, which is part of the BNL ISMS, requires enhanced work planning for work with certain hazardous materials. The enhanced work planning ensures that adequate hazard controls and completion of required training are in place before work with hazardous materials begins.

[36] http://intranet.bnl.gov/esh/cms/

The use of flammable liquids is minimal. Light industrial chemicals may be in use such as acetone, ethyl alcohol that is used as general cleaning solvent, glass cleaner, PVC cement that is used for insulation work, and spray paint. Any use of flammable liquids follows BNL SBMS requirements.

4.6.3. Electrical Safety

The requirements for electrical safety are given in detail in the BNL SBMS and the C-AD OPM. Electrical bus work is covered to reduce/prevent electrical hazards in the power supply areas. In the Prototype ERL cave, exposed conductors will not be present and magnet buss is covered. In Controlled Access mode, even though the magnets will not be powered, the power supplies will not be locked out. Workers are trained to assume that magnets are powered in all cases and to treat them accordingly. In cases where workers are required to work on or near a specific magnet during Controlled Access or Restricted Access, the magnet power supply will be locked out and tagged out by the worker.

In some cases, it will be necessary to work near magnetic elements while powered. Appropriate control over access during this mode is maintained by the Prototype ERL Operations Supervisor. Work planning, Working on or Near Energized Conductor Permits and training requirements for entrants under these circumstances address concerns for inadvertent contact with powered conductors and exposure to magnetic fields.

4.6.4. Lockout/Tagout Program

Lockout/tagout procedures are specified in the C-AD OPM. All workers will be required to train in lockout/tagout procedures at a level consistent with their position. Where electrical hazards could be present to C-AD personnel working in an area, lockout/tagout procedures are implemented only by trained and LOTO authorized personnel.

Breaker/disconnect operations as part of the LOTO follows the electrical PPE requirements of the BNL SBMS subject area, Electrical Safety, which is equal to or more restrictive than NFPA 70E in order to prevent injury from arc flash accidents.

4.6.5. Safety Reviews and Committees

Standing safety committees are utilized throughout design, construction, commissioning and operation to focus expertise on safety, environmental protection, pollution prevention and to help maintain configuration control. See Chapter 3 for details of each committee's authority and responsibility.

4.6.6. Training

Worker training and qualification is an important part of the overall ESH plan for he C-AD. Training and qualification of workers is described in the Operations Procedures Manual and the required training for individuals is defined in the BTMS. All staff personnel and experimenters require an appropriate level of training to ensure their familiarity with possible hazards and emergency conditions.

Workers are trained in radiation and conventional safety procedures at a level consistent with their positions. The number and type of training sessions/modules is assigned using a graded approach commensurate with the staff members' responsibilities, work areas, level of access, etc. An up-to-date record of worker training is kept in the BTMS database. Radiation worker access will only be allowed if adequate training is documented, except in cases of emergency. Training procedures and course documentation will be reviewed and updated periodically.

4.6.7. Personal Protective Equipment

Special clothing is used to protect workers who are exposed to the various electrical hazards and hazardous materials, including chemicals and radiation. The clothing for a particular application is selected considering the expected hazards; a variety of types of clothing is needed to meet all hazards. There are no predicted hazards that are unique to C-AD facilities; experience and compliance with DOE 10CFR851 ensure the adequacy of protective clothing in a particular application.

Respiratory protection is provided for workers who might otherwise be exposed to unacceptable levels of airborne hazardous materials, including chemicals, oxygen deficient atmospheres and radioactive materials. Respiratory protection is selected, used and maintained per OSHA 29CFR1910.134 and BNL Respiratory Protection Procedures.

4.6.8. Significant Environmental Aspects and Impacts

In support of BNL's broad mission of providing excellent science and advanced technology in a safe, environmentally responsible manner, the C-AD is committed to excellence in environmental responsibility and safety in all C-AD activities, including Prototype ERL operations and maintenance.

To provide excellent science and advanced technology in a safe and environmentally responsible manner the C-AD has, over the past 20 years, continuously reviewed the aspects of its operations in an effort to identify and accomplish waste minimization and pollution prevention opportunities. This process began in 1988 with the development of formal environmental design guides and a design review process. More recently, this effort has resulted in a further formalization of its processes under the guidelines of ISO 14001, the BNL ISO 14001 "Plus" Environmental Management System Manual, and SBMS subject areas governing ISO 14001 implementation. The BNL EMS program emphasizes compliance, pollution prevention and community outreach. Based on the aspect identification and analysis process in the Subject Area, Identification of Significant Environmental Aspects and Impacts, the following aspects are examples of significant aspects at the Prototype ERL:

- Regulated industrial waste
- Hazardous waste
- Radioactive waste
- Atmospheric discharge
- Liquid effluents (not expected to be radioactive)
- Storage/use of chemicals or radioactive material
- Soil activation (not expected to be significant)

The environmental policy as set forth by BNL in the Environmental, Safety, Security and Health Policy is the foundation on which the C-AD manages significant environmental aspects and impacts. The formal management program is called the C-AD Environmental Management System. The Environmental Management System details may be found in the C-AD OPM.[37]

The process evaluations are documented in C-AD OPM Chapter 14. Waste streams are reviewed by the C-AD Environmental Compliance Representative (ECR) and a process evaluation denoting all material inputs and outputs for the each process of Prototype ERL is on file for existing processes. While waste streams at Prototype ERL will be the same as for other accelerators in the C-AD complex, although in much less quantity, a new process evaluation is performed for each new, significant process at Prototype ERL before use.

[37] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch01/01-10-02.PDF Environmental Management Program Description Collider-Accelerator Department and Superconducting Magnet Division

4.6.9. Hazard Reduction Associated with Waste Generation and Handling

Hazards associated with handling, packaging, treating and disposing of wastes generated during operation and modification of the facility are reduced when the generation of these wastes is minimized via pollution prevention (P2) techniques. The BNL approach to P2 associated with the operation and modification of accelerators and experiments is to address it during the design and construction phase. The objective is to minimize or eliminate the anticipated costs associated with hazardous and mixed waste generation as well as the treatment and disposal of wastes and the consumption of resources in all ERL life cycle phases: construction, operation, closure and decommissioning. Dollars spent during the design phases will provide for significantly reduced total costs over the life of the facility thus making more funds available for science. The following are the main objectives of the BNL P2 program:

- Minimize the amount of hazardous, radioactive and mixed wastes that are generated
- Minimize the cost of waste management
- Comply with federal, state and local laws, executive orders and DOE orders

The C-AD has implemented a P2 program as part of its commitment to comply with the Environmental Management System and ISO 14001. C-AD facilities have been registered to the ISO standard by a third party registrar since CY 2000. Modifications to C-AD operations have helped minimize hazards and costs associated with the generation of waste streams.

4.6.10. Fire Detection, Egress, Suppression and Response

The basis of design for fire detection, egress, suppression and response has been determined by coordination with the BNL Fire Protection Engineer (FPE) and an outside consulting group. FHAs are on the C-AD website. C-AD facilities comply with DOE fire protection guidelines as well as NFPA standards, or else have approved exemptions from the local Authority Having Jurisdiction (AHJ), which is the BNL Fire Safety Committee. The system is integrated with the site-wide system and is comprised of an automatic fire detection and suppression system that includes automatic fire suppression and rapid response capability coverage by the BNL Fire Department. Sprinklers are not provided at the Building 912 ceiling or roof levels, but rather at intermediate levels and at or within enclosures, as required. Because of the low flammability of the magnets, power cables, control cables and beam diagnostic equipment, they do not have automatic fire suppression systems, except for certain areas where significant risk of programmatic disruption exists. Manual and automatic fire detection and alarm initiation devices are installed throughout the facility. Where needed, smoke and/or heat detection devices are supplemented with pressure sensitive sensors, flammable gas detectors or other advanced detection devices such as high sensitivity smoke detection (HSSD). The appropriate portable fire extinguishers are provided for manual fire fighting efforts by trained staff. Fire alarms are alarmed at the BNL Fire Department, Building 599, and at BNL Police Headquarters, Building 50, thus providing continuous coverage for rapid fire response. This will put additional professional fire fighting resources into action within a short period. Roadways around the facility help protect it from surrounding wildfires. The buildings' roofs are non-combustible metal and do not ignite from burning ash from brush fires.

The means of egress for occupants is in accordance with NFPA 101. Enclosure exhaust fans are located within the ERL ring enclosure and may be used for rapid smoke removal.

4.6.11. Routine Credible Failures

Routine credible challenges to controls associated with worker and experimenter protection and with environmental protection are further detailed in Appendix 6, Qualitative Risk Assessments.

Beam losses at Prototype ERL are sufficiently attenuated by the bulk shielding for expected routine operation. Adequate shielding is provided to meet requirements established by the Laboratory for permissible exposure to radiation workers, non-radiation trained workers and members of the public during normal machine operations. Present Prototype ERL shielding designs reduce all normal radiation levels to well below the DOE ALARA guidelines.

Exposure to nearby facilities from Prototype ERL operations is less than 25 mrem per year and only a small fraction of the permitted 5 mrem per year at the site boundary, which are the Laboratory guidelines for radiation exposure for nearby facilities and the site boundary, respectively. Radiation exposure to maintenance workers is reduced through the design of equipment to simplify maintenance and the selection of materials to minimize failures. Through such reviews, maintenance activities will be controlled to maintain radiation exposures well within the DOE annual limits, limits that are 5 to 20 times higher than the Department's ALARA guidelines.

There are no significant quantities of dispersible gaseous or liquid radioactive materials produced at Prototype ERL. Operations personnel are trained to confine, clean up and report all water spills to management. Experience indicates that periodic leaks may occur onto the concrete floor. Spilled water is sampled before release to the appropriate waste stream or is allowed to safely evaporate in place. No offsite threats to the public are present.

4.7. Evaluation of Potential Impacts to Workers, Public and Environment

The routine radiation dose to workers is well below the regulatory limits. Worker exposure to other industrial hazards such as oxygen deficiency hazard is controlled such that potential injury is improbable. Due to the short range of the radiations, the risks to the public are zero.

Worker radiation doses, even including the maximum credible beam fault dose on a frequent basis, would not cause deterministic effects such as burns or tissue damage unless an individual were in the beam enclosure during operations. The ACS, which is categorized as Safety-Significant, assures that such irradiations are not credible.

Cooling water spills are unlikely due to adherence to ASME codes and consensus design standards. Due to the lack of chemicals and dispersible radioactivity, operation of the Prototype ERL facility is anticipated to have virtually no impact on the environment.

4.8. Selection of Control Measures that Reduce Risks to Acceptable Levels

Credited controls have been selected to favor reliance on passive over active design features and to favor engineered controls over administrative controls. Mitigation of risks associated with the Prototype ERL facility is largely achieved with passive design features. The configuration of the Prototype ERL facility meets the C-AD mission of producing an intense source of pulsed electrons while satisfying safety requirements, foremost of which is the attenuation of prompt and secondary radiation. The passive shielding built into the Klystron, ring enclosure, and certain Prototype ERL structures (e.g., beam stop) was designed to passively reduce penetrating radiation to levels that are ALARA and to allow unencumbered access by users and staff in areas routinely occupied by personnel.

Active credited engineered controls are employed as needed to protect workers and users from radiation exposure, ODH and the equipment from extensive fire damage. For example, the ACS provides beam trips in response to access violations into hazardous areas or detection of elevated radiation levels in certain potentially occupied areas. Another example of an active engineered control is the ring enclosure ventilation system that activates upon ODH alarms. An example of engineered equipment protection is the sprinkler system. Proper function of active controls is ensured by required surveillance/maintenance requirements specified in the ASE.

Certain credited administrative controls have also been identified. To a large extent, required administrative controls are addressed by ISM programs already well established and maintained at BNL (e.g., radiation protection, electrical safety, etc.). Administrative controls specific to Prototype ERL are addressed by ASE requirements to ensure their safety function is maintained.

4.9. Listing of All Credited Engineered and Administrative Controls

Table 4.9.a Summary of Credited Engineered Controls

	Credited Engineered Control	Applicable Events
1	Chipmunk-interlocked beam cutoff on abnormal radiation levels	Table A.6-4 Qualitative Risk Assessment – Radiation External to Enclosure
2	Access-controlled gates	Table A.6-4 Qualitative Risk Assessment – Radiation External to Enclosure
3	Ionizing radiation shielding	Table A.6-4 Qualitative Risk Assessment – Radiation External to Enclosure
4	Fire detection and suppression systems	Table A.6-11 Qualitative Risk Assessment – Fire
5	ODH monitoring system	Table A.6-12 Qualitative Risk Assessment – Oxygen Deficiency Hazards (ODH)
6	ASME rated pressure relief valves and burst disks, ASME compliant pressure vessels and piping or equivalent	Table A.6-7 Qualitative Risk Assessment – Conventional/Industrial Hazards
7	Remote sub-station ground-fault monitoring system	Table A.6-3 Qualitative Risk Assessment – Electric Shock/Arc Flash

Table 4.9.b Summary of Credited Administrative Controls

	Credited Administrative Control	Applicable Events
1	Review of radiation safety by C-AD RSC	Table A.6-4 Qualitative Risk Assessment – Radiation External to Enclosure
2	Configuration controlled ACS drawings and computer codes; annual ACS testing	Table A.6-4 Qualitative Risk Assessment – Radiation External to Enclosure
3	Configuration controlled shield drawings and calculation codes	Table A.6-4 Qualitative Risk Assessment – Radiation External to Enclosure
4	Annual fire detection and suppression system tests	Table A.6-11 Qualitative Risk Assessment – Fire
5	ODH monitor calibrations	Table A.6-12 Qualitative Risk Assessment – Oxygen Deficiency Hazards (ODH)
6	Relief valve and burst disk maintenance according to ASME standards	Table A.6-7 Qualitative Risk Assessment – Conventional/Industrial Hazards
7	Ground-fault alarm testing	Table A.6-3 Qualitative Risk Assessment – Electric Shock/Arc Flash

4.10. Description of the Maximum Credible Incident

The maximum credible incident is the incident in terms of property loss or injury to personnel that would result assuming all installed safety systems functioned as designed.

4.10.1. Maximum Credible Fire Incident

The objectives of presenting no threats to the public health and welfare or undue hazards to life from fire are satisfied. The designs of all C-AD facilities comply with the "Life Safety Code" (NFPA 101) and NYS Building Code and with the specific requirements of the

Occupational Safety and Health Standards (CFR29, Part 1910) applicable to exits and fire protection.

Welding gases and flammable/explosive gases are used and stored according to NFPA codes and standards applicable to experimental installations. Gases are stored in compressed gas cylinders that meet Department of Transportation (DOT) specifications. Large quantities of gas are forbidden in accelerator areas. There are no off-site threats to the public should a cylinder fail.

The facility is designed with an "improved risk" level of fire protection. The design requirements that were used are found in: 1) DOE Order 420.1, Facility Safety and 2) DOE Order 6430.1A, General Design Criteria. Prototype ERL is fitted with fire detectors and fire protection systems where appropriate. Fires are expected to be extinguished by these protective systems. Combustible loading in the Prototype ERL beam cave and other power supply areas consists of magnets, power cables, control boards, control cables and beam diagnostic equipment. None of the materials are highly flammable, and with the possible exception of small amounts of control cable and circuit boards, all are expected to self extinguish upon de-energizing of electric power. Induced radioactivity is deeply entrapped in concrete shielding and is not dispersible in a fire. There are no offsite threats to the public from a fire.

The personnel risks associated with the fire hazard are acceptable considering the type of building construction, the available exits, the fire detection systems, the fire alarm systems and the relative fire-safety of the components and wiring. Emergency power and lighting is available in accordance with fire industry standards.

Travel distances to exits at Prototype ERL do not present a problem. In structures of low or ordinary hazard and in structures used for general or special industrial occupancy, NFPA 101 permits travel distances up to 120 m to the nearest exit if the following provisions are provided in full:

- Application is limited to one-story buildings only
- Interior finish is limited to Class A or B materials per NFPA definitions
- Emergency lighting is provided
- Automatic sprinklers are provided in accordance with NFPA 101 or exempted by the local AHJ
- Extinguishing system is supervised

Smoke and heat venting by engineered means or by building configuration are provided to ensure that personnel are not overtaken by spread of fire or smoke within 1.8 m of floor level before they have time to reach exits.

DOE has established limits of $1,000,000 for a Maximum Possible Loss and $250,000 for a Maximum Credible Loss mandating the installation of automatic suppression systems in locations where those limits are exceeded. Prototype ERL design meets these criteria. It is noted that Prototype ERL is an experimental facility with a limited life time that allows judgment by the AHJ in determining the fire protection requirements.

Based on previous experiences at C-AD, the predominant sources of fire initiation have come either from electrical malfunctions or overheating in beam-line components such as magnets, which have caused a break down of the electrical insulation and subsequent arcing. The maximum credible fire incident was determined by the AHJ to be a fire in one magnet and damage to the two adjacent magnets. While the klystron's 100 kV transformers have 800 gallons of oil, it was felt that smoke detectors, interlocks to turn off power to the 100 kV transformers, fire sprinklers, low-flammability oil in the transformers, secondary containment and onsite fire responders would result in a less credible fire incident.

4.10.2. Maximum Credible Electrical Accident

The electrical systems and equipment in use at Prototype ERL is the same as that in use at C-AD facilities for many years. This statement does not minimize the inherent dangers; rather, it indicates that the technical personnel are experienced on accelerator circuits and devices. Additionally, they are qualified to work on these systems. Every engineer, technician and electrician that is expected to work on the facility equipment is adequately trained. The training includes an awareness of potential hazards and knowledge of appropriate safety procedures and emergency response plans. Training is documented and a list of authorized personnel is kept on a network electronic database (BTMS) and is available to supervisors.

The C-AD staff is familiar with the types of electrical hazards that relate to the accelerators and experimental areas. All required safety features are installed in and on the electrical equipment. The groups that maintain, repair, test and operate the equipment have the knowledge, tools and experience to perform safely. Work planning, which includes electrical safety procedures, working on or near energized conductor permits and, when required for high hazard work, job safety analyses is done to adhere to the safe practices mandated by OSHA and the BNL SBMS Subject Area on Electrical Safety. Periodic retraining improves the safety margin. Thus, the potential risk for a serious electrical shock is minimized to levels currently accepted throughout the industry.

4.10.3. Risk Assessment to Workers, the Public and the Environment

4.10.3.1. Radiation Risks

The routine radiation dose to workers is well below the DOE regulatory limits of 10CFR835. The range of doses received by C-AD radiation workers in FY2007, which was a typical recent year with the RHIC nuclear physics program, was from zero to ~60 mrem. Experience shows the average exposure of C-AD radiation workers is close to zero mrem during the RHIC nuclear physics program. The dose to an average C-AD radiation worker is only a small fraction of the regulatory limit, and the increase in fatal cancer risk after a lifetime of radiation work, 50 years, is insignificant, <<0.06%[38] compared to the naturally occurring fatal cancer rate of nearly 20%. Additionally, data shows the radiation burden for the C-AD worker

[38] This assumes a risk coefficient of $4x10^{-4}$ per rem for workers from NCRP Report No. 115, Risk Estimates for Radiation Protection (p. 112) and a 50-year career at 30 mrem per year.

has been declining for the past four decades. The risks to the public are an extremely small fraction of worker risk.

Worker doses at Prototype ERL, even including the maximum credible beam fault dose on a frequent basis, would not cause deterministic effects such as burns or tissue damage unless an individual were in the Prototype ERL accelerator cave during operations. The ACS, which is categorized as Safety-Significant, assures that such irradiations are not credible.

4.10.3.2. Environmental Risks from Radiation

There are no credible risks to the environment from groundwater contamination caused by Prototype ERL operations. Any spill of the insignificant levels of radioactive cooling water from a failed pipe or hose would have no environmental impact.

4.10.3.3. Fire Risks

Based on the extensive use of fire protection as determined by the BNL Fire Protection Engineer, the appropriate location of exits and the use of emergency ventilation exhaust systems, high or medium consequence levels are extremely unlikely. Thus, the fire risk is acceptable.

4.10.3.4. Electrical Risks

Based on the use of formal C-AD electrical safety procedures, working on or near energized conductor permits and, for high hazard work, job safety analyses, high or medium consequence levels are extremely unlikely. Thus, the risk is acceptable.

4.10.4. Professional Judgment Issues

The initial screening of Prototype ERL hazards was performed using qualitative engineering judgment. The C-AD engineering, operating and safety staff has many years of experience with BNL accelerators and experiments. This experience influenced the analyses of Appendix 2.

Experience has also influenced the choice of conservative maximum hourly routine and faulted beam power limits which have been used as the bases for the shielding and ALARA analyses. These judgment issues have always been and will continue to be verified by beam fault studies.

4.10.5. Methods Used in Evaluation of Radiological Hazards

Techniques employed in the evaluation of radiological hazards include the use of empirical formulae and graphs[39] and the Monte Carlo Program MCNPX[40]. MCNPX is probably the most widely used transport Monte Carlo code.

Past radiation dose rate measurements at C-AD accelerators have been made which show that dose equivalent and activation calculations are overestimates and should be regarded as upper limits.[41]

[39] NCRP Report No. 144, Radiation Protection for Particle Accelerator Facilities

[40] L. S. Waters, Ed., "MCNPX USER'S MANUAL," LANL Report TPO-E83-UG-X-0001, (1999). See also H.G. Hughes, R.E. Prael, R.C. Little, "MCNPX – The LAHET/MCNP Code Merger," X-Division Research Note, 4/22/97. The version number of the code used in this note is 2.1.5.

[41] A.J. Stevens, "Summary of Fault Studies at RHIC." BNL C-A Dept ES&F Note 156 (2000). http://server.c-ad.bnl.gov/esfd/epstechnote.html

5. Basis for Accelerator Safety Envelope

Limits for safe operations are captured in the Accelerator Safety Envelop (ASE). The ASE summarizes specific limits for hazards not routinely encountered in an industrial operation, which in this case is ionizing radiation. In addition, the ASE summarizes limitations, in a general way, derived from federal regulations or acts, DOE Orders and consensus standards (e.g., DOE Order 420.2B, OSHA, NEPA, 10CFR851, 10CFR835 and NFPA codes).

Two documents were used as references to guide the format of the ASE and they were: BNL's template[42] and DOE's Accelerator Facility Safety Implementation Guide.[43] Page 28 in the DOE Guide, item vii, discusses alternative requirements that may be specified in an ASE, and the need for procedures to implement these alternatives if used. The suitability of alternatives applicable to the Prototype ERL ASE was determined by LESHC and by the BNL Fire Protection Engineer for accelerators at C-AD.[44] With regard to the use of 12 to 15-month intervals in the ASE, this issue was reviewed by the Radiation Protection Working Group,[45] and later documented in the BNL RadCon Manual to be at the discretion of the BNL Radiation Safety Officer.

The ASE formally establishes the set of bounding conditions on engineered and administrative systems, within which the C-AD proposes to operate the Prototype ERL. These bounding conditions are based on the safety analysis documented in Chapter 4 of the SAD. The

[42] https://sbms.bnl.gov/sbmsearch/subjarea/40/40_Exh3.cfm?ExhibitID=6366
[43] http://www.rhichome.bnl.gov/AGS/Accel/SND/420Guide/Accelerator%20Safety%20Order%20Guide%20FY05.pdf
[44] See Meeting 03-01 at http://www.rhichome.bnl.gov/AGS/Accel/SND/past_leshc_business.htm
[45] http://www.rhichome.bnl.gov/AGS/Accel/SND/RSC/AnnualInterlockTestingIssue.pdf

ASE assures the validity of the basis set of assumptions used in the safety analysis and helps ensure the physical and administrative controls used to mitigate potential hazards are in place.

DOE requires adherence to the approved bounding conditions of the ASE because it is the authorization basis for all commissioning and operations activities at the Prototype ERL.

The ASE is divided into 5 Sections, and the first and second Sections address ASE administration and the limits for ionizing radiation exposure at the BNL site as a whole. Section 3 addresses specific limits for ionizing radiation and other unique industrial hazards at the Prototype ERL. Specific ASE limits in terms of particle energy and beam power are normally used to address the ionizing radiation hazard. Other specific limits such as protection against loss from fire during periods of beam operation may be found in this section. Finally, ASE limitations in Sections 4 and 5 summarize the practices to be used to limit operational, environmental, safety and health events routinely encountered in an industrial operation.

Strict adherence to the approved bounding conditions in Section 2, 3 and 4 of the ASE is expected during all commissioning and operations activities.

The highest-level information, "Safety Envelope Limits," is documented in Section 2 of the ASE. These are site-wide BNL requirements and they are:

- Less than 25 mrem in one year to individuals in other BNL Departments or Divisions adjacent to an accelerator facility
- Less than 5 mrem in one year to a person located at the site boundary
- Off-site drinking water concentration and on-site potable well water concentration must not result in 4 mrem or greater to an individual in one year

- Less than 1250 mrem in one year to an accelerator facility staff member
- Tritium concentrations in the sanitary sewer effluent less than 10,000 pCi/L
- Radioactive liquid effluent from soil activation is to be prevented
- Airborne effluents must result in emissions less than 0.1 mrem in one year to a person at the site boundary

- Based on the BNL requirements in Section 2, "Corresponding Safety Envelope Parameters" for the Prototype ERL are documented in Section 3. These are critical operating parameters that ensure the Prototype ERL will not exceed the BNL Safety Envelope Limits. These specific parameters are derived from the safety analysis of the SAD.

Authorized alternatives are also defined in Section 3. Authorized Alternatives may be used whenever the Corresponding Safety Envelope Parameter cannot be met. For example, during periods when a fire protection system becomes temporarily inoperable due to a failed smoke detector, one may allow up to 80 hours where compensatory actions may be used. Compensatory actions are prescribed in operating procedures and must have accelerator management approval in order to be implemented.

Section 4 of the ASE specifies the limits applicable to Prototype ERL engineered safety systems requiring calibration, testing, maintenance, and inspection. The frequency of functional testing and calibration of these systems is specified in Section 4.

Section 5 is reserved for administrative controls and is termed “Operations Envelope.” As allowed for in the DOE ASO Guide G420.2-1, July 1, 2005, BNL may establish an

"Operations Envelope" within the ASE, and this is done via Section 5. According to the DOE Guide, an "Operations Envelope" serves to prevent the ASE from being exceeded. Variations of operating parameters within the "Operations Envelope" of the Prototype ERL are considered normal operations. Variation outside the "Operations Envelope" but within the ASE Sections 2, 3 and 4 merits appropriate attention; however, it does not require termination of Prototype ERL activities or notification of DOE.

5.1. Connection between Engineered and Administrative Bounding Conditions and ASE

Radiation shields for the electron gun, beam dump and accelerator ring are adequate to attenuate ionizing radiation from these sources to less than BNL Safety Envelope Limits in the ERL ASE.

Radiation safety interlocks have to be tested and maintained as part of the Access Control System. Interlocks shut down beam and maintain personnel exposures with the BNL Safety Envelope Limits in the Prototype ERL ASE.

Unauthorized accesses through interlocked doors that lead into the accelerator enclosure shut down beam and maintain personnel exposures within the BNL Safety Envelope Limits in the Prototype ERL ASE.

The engineered method to prevent fault levels of radiation outside the shielded enclosure is accomplished by an appropriate distribution of area radiation monitors. Interlocks shut down beam and maintain personnel exposures with the BNL Safety Envelope Limits in the Prototype ERL ASE.

The engineered fire protection system limits in the ASE limit Prototype ERL programmatic loss to a level consistent with the highly protected risk status in private industry, as required in DOE Order 420.1B, Facility Safety.

The calibration, testing, maintenance and inspection limitations in the ASE for the engineered ODH monitoring system, radiation monitoring system, access control system, fire protection system, pressure relief devices and ODH-related ventilation system meet consensus standards and regulatory requirements in 10CFR851 and 10CFR835.

The operations envelop / administrative limits in the Prototype ERL ASE for control room staffing, training and qualification, work planning, configuration control, environmental management and worker safety and health meet requirements in DOE Orders 5480.19, 420.2B, 5400.5, 450.1, 435.1, 420.1B, 414.1C, 243.1 and in 10CFR851 and 10CFR835 and requirements in BNL SBMS Subject Areas.

5.2. ASE Consideration for Routine and Non-Routine Operating Conditions

The ASE has bounding parameters to control beam loss, classify radiological areas, and control access to radiological areas. Beam faults are terminated by radiation monitors. The ASE requires interlocking radiation monitors and routine radiation surveys in occupied areas in order to minimize radiation exposures where practicable. Routine radiological areas, radiological barriers, ALARA and radiological work are further bounded in the ASE by requiring Prototype ERL to meet requirements in the BNL Radiological Control Manual.

6. Quality Assurance

6.1. The Ten Management, Performance and Assessment Criteria of DOE O 414.1C

The criteria below are followed and are further explained in the referenced sections:

- Criterion 1- Quality Assurance Program (see Section 6.2)
- Criterion 2 - Personnel Training and Qualification (see Section 6.3.1)
- Criterion 3 - Quality Improvement (see Section 6.3.2)
- Criterion 4 - Documents and Records (see Section 6.3.3)
- Criterion 5 - Work Processes (see Section 6.3.4)
- Criterion 6 – Design (see Section 6.4.1)
- Criterion 7 – Procurement (see Section 6.4.2)
- Criterion 8 - Inspection and Acceptance Testing (see Section 6.4.3)
- Criterion 9 - Management Assessment (see Section 6.5)
- Criterion 10 - Independent Assessment (see Section 6.6)

6.2. Quality Assurance (QA) Program at Prototype ERL

The C-AD and the Prototype ERL project have adopted, in its entirety, the BNL Quality Assurance Program. This QA Program describes how the various BNL management system processes and functions provide a management approach that conforms to basic requirements defined in DOE Order 414.1C, Quality Assurance.

The quality program embodies the concept of the "graded approach," i.e., the selection and application of appropriate technical and administrative controls to work activities, equipment and items commensurate with the associated environment, safety, security and health risks and programmatic impact. The graded approach does not allow internal or external requirements to be ignored or waived, but does allow the degree of controls, verification, and documentation to be varied in meeting requirements based on risk. Any variation from external safety requirements and consensus standards must be done in accordance with the processes allowed in 10CFR851, Worker Safety and Health Program. The BNL QA Program is implemented within the Prototype ERL project using C-AD QA implementing procedures. These procedures supplement the BNL SBMS documents for those QA processes that are unique to the C-AD. C-AD procedures are maintained in the C-AD Operations Procedures Manual. These procedures establish an organizational structure, functional responsibilities, levels of authority, and interfaces for those managing, performing, and assessing work. They also establish management processes, including planning, scheduling, and providing resources for work.

The C-AD QA philosophy of adopting the BNL Quality Program and developing departmental procedures for the implementation of quality processes within C-AD ensures that complying with requirements is an integral part of the design, procurement, fabrication, construction and operation of the Prototype ERL.

A Quality Representative serves as a focal point to assist C-AD management in implementing QA program requirements. The Quality Representative has the authority, unlimited access, both organizationally and facility-wise, as personnel safety and training allows, and the organizational freedom to:

- assist line managers in identifying potential and actual problems that could degrade the quality of a process/item or work performance
- Recommend corrective actions
- Verify implementation of approved solutions

All ERL personnel have access to the C-AD Quality Representative for consultation and guidance in matters related to quality.

6.3. QA Activities That Impact Protection of Worker, Public or Environment

6.3.1. Personnel Training and Qualifications

The BNL Training and Qualification Management System within the SBMS supports C-AD management's efforts to ensure personnel working at the Prototype ERL are trained and qualified to carry out their assigned responsibilities. The BNL Training and Qualification Management System is implemented within the C-AD with the C-AD Training and Qualification Plan of Agreement. C-AD provides continuing training to personnel to maintain job proficiency.

6.3.2. Quality Improvement

C-AD has established and implemented processes to detect and prevent problems with the quality of the work and vendor purchases. The Department identifies, controls, and corrects items, services, and processes that do not meet established requirements. ERL staff identifies the causes of problems, and includes prevention of recurrence as a part of corrective action planning. The Department has programs to periodically review item characteristics, process implementation, and other quality-related information to identify items, services, and processes needing improvement.

The BNL Quality Management System, supplemented by C-AD procedures, provides the requirements to identify, document and disposition nonconformance and to establish appropriate corrective and preventive actions that are based on identified causes. The BNL Quality Management System provides guidance for trending nonconformance to recognize recurring, generic or long-term problems.

The decision to initiate quality improvement is based upon an evaluation of the seriousness, and the adverse cost, schedule, safety and environmental impact of the nonconformance relative to the cost and difficulty of its correction. In some cases, corrective action of a nonconformance may not be feasible in the near term, and equivalent protections are used.

The C-AD Self Assessment Program provides information on scientific, business and operational performance for management, staff, customers, stakeholders and regulators associated with Prototype ERL. Self-assessment also provides a mechanism for improving the rules that govern training and qualifications, documents and records, work process, design, procurement, inspection and testing, and the assessment process itself. The Self-Assessment program evaluates performance relative to critical outcomes and internal performance objectives in order to identify strengths and opportunities for improvements.

6.3.3. Documents and Records

The C-AD prepares, reviews, approves, issues, uses, and revises documents to prescribe processes, specify requirements, or establish design for the Prototype ERL. Additionally, the C-AD specifies, prepares, reviews, approves and maintains Prototype ERL records.

The BNL Records Management System and controlled document Subject Areas within SBMS, supplemented by C-AD procedures, provide the requirements and guidance for the development, review, approval, control and maintenance of documents and records.

Prototype ERL documents encompass technical information or instructions that address important work tasks, and describe complex or hazardous operations. They include plans, procedures, instructions, drawings, specifications, standards and reports.

Records are information of any kind and in any form, created, received and maintained as evidence of functions, policies, decisions, procedures, operations, or other activities performed within the Department. Records are retrievable for use in the evaluation of acceptability, and verification of compliance with requirements. Department records are protected against damage, deterioration or loss.

6.3.4. Work Process

Work is performed employing processes deployed through the BNL SBMS. SBMS Subject Areas are used to implement BNL-wide practices for work performed. Subject Areas are developed in a manner that provides sufficient operating instructions for most activities. However, C-AD management via the DOE Conduct of Operations Agreement is required to operate the accelerator complex using facility specific procedures and a Departmental chain of command. Procedures provide C-AD and prototype ERL managers with a critical management tool to communicate detailed expectations for how individual workers are to perform specific tasks. Internal technical procedures are bounded by the requirements established by the BNL Subject Areas. Technical procedures and checklists tend to follow the DOE Standard 1029-92, Writer's Guide for Technical Procedures. Departmental policy and goal-setting documents are also written in the form of procedures, and they follow this same Writer's Guide where applicable; however, they are more narrative in style.

Group leaders and technical supervisors are responsible for ensuring that employees under their supervision have appropriate job knowledge, skills, equipment and resources necessary to accomplish their tasks. C-AD and Prototype ERL subcontractors and vendors are held accountable to implement this same practice.

The BNL Quality Management System, supplemented by C-AD procedures, provides processes for identifying and controlling items and materials to ensure their proper use and maintenance to prevent damage, loss or deterioration.

C-AD management has identified those processes requiring calibrated measuring and testing equipment. Item identification and control requirements are specified, when necessary, in appropriate documents, e.g., drawings, specifications and instructions. Materials undergoing tests or inspections are controlled to avoid mixing acceptable items with items of unknown origin or history, thus avoiding inadvertent use.

C-AD management delegates authority to all C-AD personnel to "Stop Work" to avoid unsafe work practices.

6.4. QA Activities That Impact Accelerator Maintenance and Operations

6.4.1. Design

The C-AD staff plans, develops, defines and controls the design of the Prototype ERL in a manner that assures the consistent achievement of objectives for productivity, performance, safety and health, environmental protection, reliability, maintainability and availability. Design planning establishes the milestones at which design criteria, standards, specifications, drawings and other design documents are prepared, reviewed, approved and released.

The design criteria define the performance objectives, operating conditions, and requirements for safety and health, reliability, maintainability and availability, as well as the requirements for materials, fabrication, construction, and testing. Appropriate codes, standards and practices for materials, fabrication, construction, testing, and processes are defined in the design documentation. As indicated in 10CFR851, nationally recognized codes and consensus standards are used. If national consensus codes are not applicable because of experimental restrictions, then C-AD implements appropriate approved processes to provide equivalent protection. In this way, C-AD and Prototype ERL ensure a level of safety greater than or equal to the level of protection afforded by the national codes and standards.

Specifications, drawings and other design documents are used to represent verifiable engineering delineations, in pictorial and/or descriptive language, of parts, components or assemblies in the Prototype ERL. These documents are prepared, reviewed, approved and released in accordance with C-AD procedures. Changes to these documents are processed in accordance with the C-AD configuration management procedures.

6.4.2. Procurement

Personnel responsible for the design or performance of items or services to be purchased ensure that the procurement requirements of a purchase request are clear and complete. Using the graded approach, potential suppliers of critical, complex, or costly items or services are evaluated in accordance with predetermined criteria to ascertain that they have the capability to provide items or services that conform to the technical and quality requirements of the procurement. The evaluation includes a review of the supplier's history with BNL or other DOE facilities, or a pre-award survey of the supplier's facility. C-AD personnel ensure that the goods or services provided by the suppliers are acceptable for their intended use.

6.4.3. Inspection and Acceptance Testing

The BNL Quality Management System within the SBMS, supplemented by C-AD procedures, provides processes for the inspection and acceptance testing of an item, service or process against established criteria and provides a means of determining acceptability. Based on the graded approach, the need and/or degree of inspection and acceptance testing are determined during the activity/item design stage. Inspection/test planning has as an objective the prompt detection of nonconformance that could adversely affect performance, safety, reliability, schedule or cost.

When required, acceptance and performance criteria are developed and documented for key, complex or critical inspection/test activities. If an item is nonconforming, it is identified to avoid its inadvertent use. These processes specify how inspection and test status are indicated either on the item itself, or on documentation traceable to the item.

The BNL Calibration Subject Area, supplemented by C-AD procedures, describes the calibration process for measuring and test equipment. Prototype ERL management identifies appropriate equipment requiring calibration. The calibration status is readily discernible and associated calibration procedures, documentation, and records are prepared and maintained. Calibrated equipment is properly protected, handled and maintained to preclude damage that could invalidate its accuracy. Measuring and test equipment found out of calibration is identified and its impact evaluated.

6.5. Management Assessment

The managers of the four C-AD Divisions periodically evaluate or "self-assess" the effectiveness of the C-AD organization and present their report to senior management. Through the C-AD Self-Assessment Program, a regular, systematic evaluation process has been established wherein C-AD assesses internal management systems and processes used to make fact-based decisions. For example, see the C-AD Assessment Web Page. The C-AD Self-Assessment Program extends to the operation of the Prototype ERL and includes such items as: performance measures; compliance checks; effectiveness evaluations; job assessments; surveys; and environment, safety and health walk-throughs. Strengths and opportunities for improvement are identified. Assessment results are documented and fed back to managers, and provide valuable input into the business-planning process.

C-AD's Environment Management System and Occupational Safety and Health (OSH) Management System and associated activities also undergo management review each year. In addition, these management systems are reviewed by third-party registrars, and federal, New York State and County agencies. Together these reviews provide comprehensive and objective information used by C-AD management in establishing strategic direction and improving environmental and OSH performance.

6.6. Independent Assessment

Using the graded approach, C-AD management periodically evaluates the implementation of the BNL Management Systems, SBMS Subject Areas and Department-level procedures. This is done through reviews, assessments and/or other formal means. The C-AD QA Group performs these assessments. They include an evaluation of the safety and quality cultures in terms of the adequacy and effectiveness of the management structure, which includes, but is not limited to, environment, safety and health, security, quality, conduct of operations, and training requirements.

Individuals verifying these activities have sufficient authority to access work area, and organizational freedom to accomplish the following: identify problems, initiate, recommend, or provide solutions to problems through designated channels, and verify implementation of solutions.

All assessments are planned and conducted using established criteria. The type and frequency of these assessments are based on the status, complexity and importance of the work or process being assessed. The results are documented, non-conformances and recommendations identified and presented to C-AD management. The Department develops corrective actions to promote improvement. Actions are tracked to closure by C-AD QA in the Family version of the BNL Assessment Tracking System (ATS). Those conducting independent assessments are technically qualified and knowledgeable in the areas assessed and are independent from the activities assessed. Where necessary, subject matter experts are involved in the assessments to give insight into a particular area.

In addition, peer review is a process used at C-AD by which the quality, productivity and relevance of science and technology programs is monitored and evaluated. In operational and ESH arenas, peer review is used to evaluate and independently verify engineering design and procedure implementation.

7. Post-Operations Planning

7.1. Structural and Internal Features that Facilitate Future Decommissioning/Dismantling

Concrete block was used to create the walls and labyrinths for the Prototype ERL. See the figure below. This concrete is re-usable and when not in use, it is stacked inside Building 912.

Additionally, significant portions of the following items are likely to be recycled or reused:

- Superconducting RF Cavity - The 5-cell SRF cavity may be used in RHIC. If C-AD does not use it in RHIC, the cryostat will still be useable.
- RF Systems for Superconducting Injector and Superconducting Cavity will be re-used.
- The laser system used for the Prototype ERL will be reused. Slight modifications may be needed if there are changes in the operating parameters. The same would be true for the

optical components. Neither the laser nor the optical components produce radioactive or hazardous waste.

- Cryogenic, vacuum, magnet and electrical hardware outside the accelerator enclosure will be re-used.
- The Prototype ERL electron beam dump system will be used as a spare for the RHIC electron beam cooler. The dump is made of Cu and 304L stainless steel; it has an Al support structure with G-10 insulators. Low levels of activation are expected.
- Beam instrumentation will be re-used.
- Conventional facilities (e.g., cables, electrical distribution panels, cable tray) will be reused.

7.2. Operations Considerations to Minimize the Generation of Radiological and/or Hazardous Materials

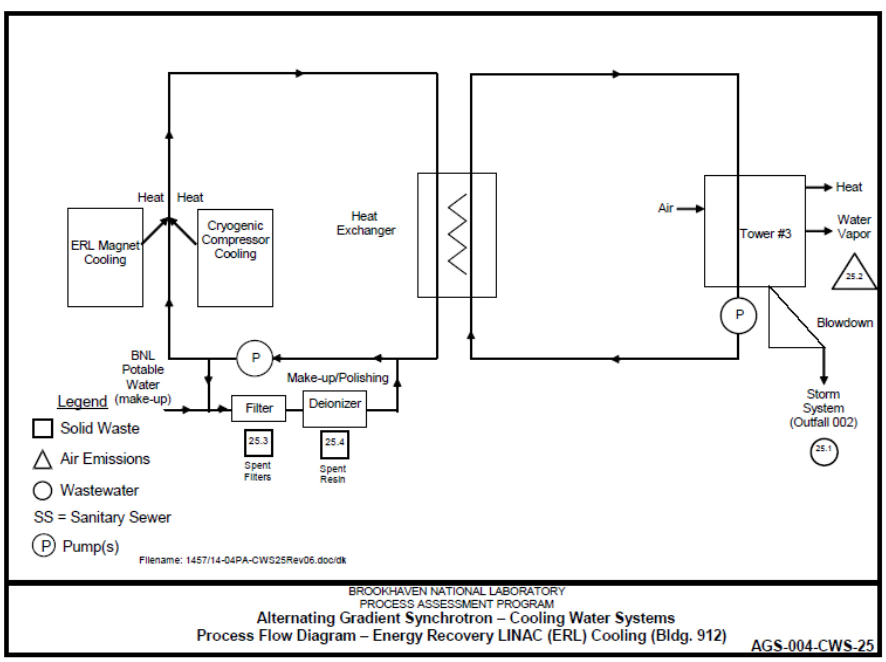
The C-AD participates in ISO 14001 registrations each year for environmental management and conducts a review of all existing process assessments and performs an initial assessment for each new process introduced in that year. Each assessment consists of the following topics:

- Detailed process descriptions and waste determination
- Regulatory determination of process outputs
- Waste minimization, opportunities for pollution prevention
- Assessment prevention and control for hazardous and radioactive materials

For example, the Prototype ERL closed-loop cooling water system transfers heat from the Prototype ERL magnets and cryogenic compressors to cooling water and then indirectly rejects the heat utilizing a heat exchanger to cooling tower #3 (see Figure 7.2). Cooling water from tower #3 directly rejects heat to air utilizing the cooling tower. Based on the process assessment, the following practices were implemented at Prototype ERL in order minimize the generation of and on-site storage of radioactive and hazardous materials:

- Water drained or otherwise collected from the Prototype ERL primary loop is collected in tanker trailers where it is stored for reuse/recycle, or evaporated or disposed of as radioactive waste
- No biocide or corrosion inhibitors are added to the Prototype ERL water system
- Spent filters are sent offsite for disposal as low-level radioactive waste every 1 to 2 years
- Spent deionizer resin is exchanged onsite approximately every two years and the resins are drummed, sampled and disposed based on sample analysis results

Figure 7.2 Prototype ERL Cooling Water Process Flow Diagram



In addition to cooling water, this type of process evaluation is done for all Prototype ERL related operations that use or generate hazardous and radioactive materials including:

- Beam line construction and disassembly
- Magnet cleaning
- Electronic assembly
- Beam stops and collimators
- Materials storage
- Mechanical assembly
- Plating and tinning
- Cryogenic systems
- Vacuum systems
- Tech shop activities

7.3. Long-Term Records Management to Facilitate Post-Operations Activities

The following line-organization records are maintained to facilitate post operation activities:

ERL Records to Facilitate Post-Operations Activities

Topic
Occupational Health & Safety Management System Description
Occupational Health & Safety Management Plans
Risk Assessments Files
OSH Management Reviews And OSH Records Of Decision Documents
OSH Internal Assessments and Audits
WOSH Committee Records (Worker Safety Committee)
Training Records
Safety Committee Records
Local Emergency Planning Documents
Emergency Contingency Plans
Tier 1 Facility Safety Inspections
Safety Assessment Documents and Safety Analysis Reports
Work Planning And Control Documentation
Environmental Permits
Experimental Safety Reviews
Occurrence Reports
Operating Manuals
Safety Equipment Records
Records of Roles, Responsibilities, Authorities and Accountabilities for Employees
Process Assessments
Environmental Assessments
Cooling Water System Records
Maintenance Records

7.4. Waste Management of Radiological and Hazardous Material Generation During Post Operations Period

Waste management post Prototype ERL operations will be based on radiological conditions at the time of final shutdown of the Prototype ERL. The approach will factor in the effectiveness of the methods to achieve the desired end-point of the remaining facility. Much of the Prototype ERL facility, such as support buildings and control areas, do not have radioactive or hazardous materials and will require only standard waste management techniques. Based on the projected low-levels of activation of beam line components, they will be able to be contact handled. A post operations waste management plan will be developed at the end of the Prototype ERL facility's life. The plan will address the conditions and hazards in detail and will have the benefit of additional information and waste management technologies not yet available.

8.References/Glossary/Acronyms

8.1. List of Documents that Provided Supporting Information for the SAD

8.1.1. Accelerator Safety Implementation Guide for DOE O 420.2, Safety Of Accelerator Facilities, Office of Science, Department of Energy, May 1999.

8.1.2. Accelerator Safety Subject Area

8.1.3.C-AD Conduct of Operations Matrix

8.1.4.C-AD Fire Hazards Analyses

8.1.5.OPM for C-AD

8.1.6. Radiological Control Manual

8.2. List of Acronyms

AC – Alternating Current

ACGIH – American Conference of Governmental Industrial Hygienists

ACS – Access Control System

AHJ – Authority Having Jurisdiction

AISC - American Institute of Steel Construction

ALARA – As Low As Reasonably Achievable

ANSI – American National Standards Institute

ASE – Accelerator Safety Envelope

ASME - American Society of Mechanical Engineers

ASSRC – Accelerator Systems Safety Review Committee

ASTM - American Society for Testing and Materials

ATS – Assessment Tracking System

AVS – American Vacuum Society

AWS – American Welding Society

BHSO – Brookhaven Site Office

BNL – Brookhaven National Laboratory

BSA – Brookhaven Science Associates

BTMS – Brookhaven Training Management System

C-AD – Collider-Accelerator

CA – Controlled Access

CAS – Collider-Accelerator Systems Watch

CEE – Chief Electrical Engineer

CFR – Code of Federal Regulations

CGA – Compressed Gas Association

CME – Chief Mechanical Engineer

CW – Continuous Wave

DC – Direct Current

DI – De-ionizer

DOE – Department of Energy

DOELAP – DOE Laboratory Accreditation Program

DOT – Department of Transportation

ECR – Environmental Compliance Representative

EMS – Environmental Management System

EPA – Environmental Protection Agency

ERL – Energy Recovery Linac

ES&F – Experimental Support and Facilities Division

ESH – Environment, Safety and Health

ESHQ – Environment, Safety, Health and Quality

ESRC – Experimental Safety Review Committee

ESSHQ – Environment, Safety, Security, Health and Quality

FHA – Fire Hazards Analysis

FPE – Fire Protection Engineer

FUA – Facility Use Agreement

HOM – Higher Order Mode

HSSD – High Sensitivity Smoke Detector

HV – High Voltage

HVAC – Heating, Venting and Air Conditioning

IOC – Input Output Controller

ISM – Integrated Safety Management

ISO – International Standards Organization

LE – Liaison Engineer

LEC – Local Emergency Coordinator

LOTO – Lock Out / Tag Out

LP – Liaison Physicist

MCNPX – Monte Carlo Neutron Photon Transport Computer Codes

MCR – Main Control Room

MLI – Multi-Layer Insulation

MPFL - Maximum Possible Fire Loss

MS – Management System

NEBA - Northeast Building Addition

NEPA – National Environmental Policy Act

NESHAP - National Air Emission Standards for Hazardous Air Pollutants

NFPA – National Fire Protection Association

NRTL – Nationally Recognized Testing Laboratory

NYS – New York State

ODH – Oxygen Deficiency Hazard

OPM – Operations Procedure Manual

ORPS – Occurrence Reporting and Processing System

OSH – Occupational Safety and Health

OSHA – Occupational Safety and Health Administration

P2 – Pollution Prevention

PCSS – Pressure and Cryogenic Safety Subcommittee

PE – Plant Engineering

PLC – Programmable Logic Controller

PPE – Personal Protective Equipment

QA – Quality Assurance

R2A2 – Roles, Responsibilities, Accountabilities and Authorities

RadCon – Radiological Control

RCT – Radiological Control Technician

RF – Radio Frequency

RFQ – Radio Frequency Quadrupole

RHIC – Relativistic Heavy Ion Collider

RSC – Radiation Safety Committee

RWP – Radiation Work Permit

S&T – Science and Technology

SAD – Safety Assessment Document

SBC – Standard Building Code

SBMS – Standards Based Management System

SCDHS – Suffolk County Department of Health Services

SCFM – Standard Cubic Feet per Minute

SFPC – Standard Fire Prevention Code

SPDES – State Pollution Discharge Elimination System

SRF – Superconducting RF

TLD – Thermo-Luminescent Dosimeter

UL- Underwriters Laboratories

UPS – Uninterruptible Power Supply

WOSH – Worker Occupational Safety and Health

APPENDIX 1

Shielding Analyses

Simple Estimate of ERL Radiation
D. Beavis
August 1, 2006
Updated August 9, 2006

Simple estimates are made for the potential radiation sources in the ERL R&D test setup. The dose rates are based on thick target formulas for high Z targets. The dose rates should be a conservative estimate of the dose rates that could occur due to beam losses. The goal is to obtain an overall view of the shielding issues at an order of magnitude level.

3.5 MeV Electron Beam

Recently the maximum electron gun energy has been lowered from 5 MeV to 3.5 MeV. The potential radiation from beam losses can be estimated from thick target curves given in various references (see ref. 1). The numbers are given at 1 meter from a localized source.

3.5 MeV e- losses rad/(hr-kW)

0 degrees	$4*10^4$
90 degrees	$8*10^3$

The 3.5 MeV beam has a maximum power of 1000 kW. The beam will be transported to the beam dump. The dump must have local shielding to reduce this to levels that are appropriate for the shielding enclosure. The energy of this beam is too low to generate neutrons.

25 MeV Electron Beam

Recently the electron beam energy for the ERL ring has been lowered from 54 MeV to 25 MeV. Using the same reference and assumptions the dose rates at 1 meter are:

25 MeV e- losses rad/(hr-kW)

0 degrees	$8*10^5$
90 degrees	$8*10^3$

The beam energy is sufficiently high in energy to generate neutrons via giant dipole resonance. It will be assumed that the target material is iron. The neutrons are essentially isotropic. The dose rate at 1 meter is (see ref 2):

Neutrons rem/(hr-kW)
430

Non-Beam Sources

The electron gun and the 5-cell accelerating cavity will generate x-rays. The level of x-rays is uncertain but it is assumed that they will be capable of generating dose rates similar to the RF cavities at RHIC. The RHIC observed dose rate of **100 rad/hr at 1 meter** will be assumed.

Beam Losses

The 3.5 and 25 MeV beams are expected to operate with low routine losses. The 5 MeV beam will have a collimator, which will most likely require local shielding. The beam dump will be designed for absorbing the entire 1000 kW of 3.5 MeV beam. The routine loss is expected to be low after the collimator. The power supply system is capable of generating sufficient power to sustain a 1 MW accidental loss. However, large accidental losses may cause damage, which terminates the operation. It is not clear what limits on the beam losses will cause self-termination. Until a self-limiting mechanism is understood we will assume 1 MW can be sustained. Routine losses at unshielded locations are expected to be less than 1 W. The maximum sustainable loss of the 25 MeV beam has been established as 50 kW, which is the limit of the RF power supply. The 25 MeV beam is expected to have routine losses at least a 1000 times lower than the max. sustainable loss, i.e. 50 W.

It is proposed that two beam current transformers be used in differential mode to limit the level of routine losses for both the 3.5 MeV and 25 MeV beams. The first transformer will be located after the collimator in the 3.5 MeV transport. The second will be located in the 3.5 MeV transport to the beam dump. Comparing the difference will establish a net loss of beam in both the 3.5 and 25 MeV transports between the transformers. The plan is to have the configuration of this transformer system under the control of the access control group similar to the B20 transformers in the AGS. A specification will be prepared and presented to a vendor to see if it is achievable. It will be assumed that the system will be accurate for differences of 10^{-3} (conservative) and it is hoped that it will be capable of measuring differences of 10^{-6}. The table below summarizes (crudely) the present sustainable losses for the beams:

Beam (MeV)	Beam Power (kW)	Max. Sustainable loss (kW)	Max. Sustainable loss with transformer at10^{-3}
3.5	1 MW	1 MW	1 kW
25	10MW	50 KW	10 kW

We can use this table to generate the maximum sustainable radiation dose rates from beam losses. These numbers are summarized in the table below:

Dose rates at 1 meter in rad/hr (rem/hr for neutrons)

condition	Max. Loss	Max. Loss with transformer (10^{-3})	Routine
3.5MeV@ 0 deg.-ph	$4*10^7$	$4*10^4$	40
3.5MeV@ 90 deg.-ph	$8*10^6$	$8*10^3$	8
25 MeV@ 0 deg.-ph	$4*10^7$	$8.*10^6$	$4*10^4$
25 MeV @ 90 deg-ph	$4*10^5$	$8.*10^4$	$4*10^2$
25 MeV- neutrons	$2.1*10^4$	$4.3*10^3$	$2.1*10^1$

Radiation Through Shield Walls

The radiation levels outside the shield walls can be estimated using "tenth-value layers" (TVL) given for broad beams of electrons and neutrons on shielding material. For the photon shielding the values used for forward (zero-degree) shielding are (see ref. 3):

Energy-material	First TVL (gm/cm^2)	Equilibrium TVL (gm/cm^2)
3.5 MeV- Concrete	60	60
3.5 MeV- Fe	67	67
3.5 MeV- Pb	55	55
25 MeV- Concrete	120	110
25 MeV- Fe	85	85
25 MeV- Pb	60	60

For 25 MeV electrons the TVLs for concrete at 90 degrees are substantially smaller than above and are 85 gm/cm^2 for the first TVL and 80 gm/cm^2 for the following layers (see ref. 4).

The neutron TVLs for concrete (see ref. 5) that are used are 100 gm/cm^2 for the first TVL and 80 gm/cm^2 for all other layers.

The source terms need to be scaled to the expected dose rate at the shielding wall. A distance of 3 meters will be used for this purpose, which is an appropriate distance for the beam line close to the shield wall. This gives a reduction of 1/9. It is then assumed that the dose rate is constant across the portion of wall and the attenuation of the shielding is calculated using the TVLs. The concrete walls are 48 inches thick (287 gm/cm^2).

Dose rates outside 48 inch Concrete Shield (3 meters from source)

condition	Max. Loss	Max. Loss with transformer (10^{-3})	Routine
3.5MeV@ 0 deg.-ph	73 rad/hr	73 mrad/hr	0.07 mrad/hr
3.5MeV@ 90 deg.-ph	15 rad/hr	15 mrad/hr	0.01 mrad/hr
25 MeV@ 0 deg.-ph	13,000 rad/hr	2600 rad/hr	13 rad/hr
25 MeV @ 90 deg-ph	13 rad/hr	2.7 rad/hr	13 mrad/hr
25 MeV- neutrons	1.2 rem/hr	240 mrem/hr	1.2 mrem/hr

The present shielding coupled with the loss assumptions is not sufficient for the photons generated by the 25 MeV electron beam. The beam current transformer interlock and chipmunks outside the shielding probably provide acceptable protection for the other operating conditions. 2-4 orders of magnitude more attenuation for the high-energy photons is required. 10^{-2} attenuation in the forward direction requires 37 inches of concrete, or 8.7 inches of steel, or 4.3 inches of Pb. This would require a thicker shield wall or shielding placed close to the beam line to shield the forward losses.

The present shielding for 90-degree losses of the 25 MeV electron has an attenuation of $3*10^{-4}$. This will be useful for comparison with the attenuation through penetrations in the shielding.

Straight Penetrations Through the Shielding

A simple discussion of the attenuation of straight holes in shielding can be found in Sullivan (see ref. 6). For directional radiation the attenuation depends on the angle between the direction of the radiation and the axis of the hole. For the 90-degree losses most of the penetrations at the ERL R&D test area are at about 45 degrees (close loss) and 24 degrees (far loss). The attenuation for the smaller angle is less but the increased distance to the source also reduces the radiation. For the present discussion the data at 45 degrees will be used with the source evaluated at 3 meters. As can be seen from ref. 6 figures 2.25 and 2.26 the attenuation of neutrons and photons is similar for these angles and the attenuation given for hadrons in ref. 6 figure 2.27 will be used. In addition a formula for neutrons given by Goebel (see ref 7) is used. The attenuation for penetrations through the 48 inch shield wall are listed by the diameter area below:

Diameter (in)	Area (in^2)	Attenuation via Sullivan	Attenuation via Goebel
2	3	$1.2*10^{-3}$	$5.6*10^{-5}$
4	12	$7*10^{-3}$	$5*10^{-4}$
8	49	$4*10^{-2}$	$3.7*10^{-3}$
12	108	$1.1*10^{-1}$	$1.1*10^{-2}$

The Goebel formulation gives attenuations about a factor of 10 smaller than Sullivan. The Goebel formula appears to agree with the values of Sullivan at larger angles, about 75 degrees. For now we will use the more conservative number of Sullivan. The two-inch diameter penetration would have a dose rate about 4 times higher than the shield wall for 25 MeV electron large angle losses. This would probably be acceptable but is not a useful size. The larger holes could be acceptable provided personnel cannot occupy the area near the penetration exit. This simple treatment does not include contributions from reflections from surfaces. Many of the penetrations are near the ceiling and can obtain contributions from radiation reflecting off the ceiling.

Several of the straight penetrations are substantial in size and personnel can approach the exit of the penetration while the machine is operating. These are of special concern and are listed below:

Penetration	Area (in^2)
Cable tray into second floor	288
Wave guide for 5-cell cavity	90
Wave guide for RF-Gun	288

These penetrations are sufficiently large in area and short that they provide essentially no attenuation and require reconsideration. The cable tray port could be divided into distributed smaller ports. The wave-guides must remain the same dimension and therefore the only option to improve the attenuation is to make these penetrations as multi-legged penetrations. Where possible all penetrations should be multi-legged.

Multi-legged Penetrations

The attenuation of neutrons in a multi-legged labyrinth can be calculated using the formulation of Goebel. A penetration for the wave-guide with dimensions 8 inches high by 12 inches wide and with two 18-inch long legs and one 48-inch long leg has an attenuation for neutrons of $1.1*10^{-5}$. The attenuation of photons through the labyrinth should be smaller since the reflection coefficients are smaller for photons than neutrons (see ref. 8). The design of the bends must take into account the potential for neutrons or photons to penetrate through the walls of the bends and "short-circuit" the labyrinth ("punch-through").

There are 4 existing multi-legged labyrinths at present in the shielding. Personnel and equipment access ways are located at the north and south ends of the test area. A utility trench exits under the east and west walls at the south end of the area. The two access ways have been crudely estimated assuming they are 3-legged labyrinths with a factor of 4 to account for the increased size of the openings. The attenuation for each access way is a few 10^{-3} attenuation with a large error. When treated as a two-legged labyrinths the access ways have attenuations of a few 10^{-2} . The attenuations for photons should be lower as noted above. These should be evaluated more carefully in the future. The two trench exits are not calculated here since the geometry does not lend easily to a labyrinth formula. They need to be evaluated in the future or since they are not be used blocked with shielding.

Conclusions

Simple techniques have been used to make simplistic estimates of the dose rates due to beam losses in the ERL R&D test area. Most of these estimates can be considered conservative and offer a general guide for resolving the open issues in the shielding design. These estimates are not intended to replace detailed Monte Carlo calculations where needed. The main unresolved issues at present are the shielding of the photons in the forward direction, the straight penetrations, and the cracks (not discussed here).

References

1) NCRP Report No. 144, Figure 3.5.
2) NCRP Report No. 144, Figure 3.12, and a flux to dose conversion factor.
3) NCRP Report No. 144, Figure 4.1.
4) NCRP Report No. 144, Table 4.2.
5) W.P. Swanson, Radiological Safety Aspects of the Operation of Electron Linear Accelerators, 1979, Figure 52.
6) A.H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, 1992.
7) K. Goebel et. al., "Evaluating Dose Rates Due to Neutron Leakage Through the Access Tunnels of the SPS", CERN LABII-RANote/75-10(1975).
8) NCRP Report No. 144, Figures 4.12 and 4.13.

The effectiveness of a Two-Foot Thick Inner Heavy Concrete Wall

D. Beavis
Dec. 11, 2006

The outside shield wall of the ERL test area is four feet of light concrete. This shield does not provide sufficient (ref. 1) attenuation for the potential radiation from forward faults of the 25 MeV electron beam. Various schemes have been suggested for introducing shielding close to the beamline for additional radiation reduction. In this note the effectiveness of using two feet of heavy concrete as an inner shield wall will be examined. It will be concluded that this should provide sufficient reduction of the radiation.

MCNPX (Ref. 2) can be used to estimate the dose due to photons. Azimuthal symmetry will be used for the problem. The front face of the target is placed 300 cm in front of the four feet thick light concrete shield wall. The 25 MeV beam strikes the front of the target with a direction perpendicular to the shield wall. Initial calculations are done with the existing light concrete wall and then a two feet thick layer of heavy concrete is added 1 meter from the target. The photon doses are tallied on the inner and outer surface of the light concrete wall.

The composition of heavy concrete was obtained by supplementing the composition of the light concrete with iron to achieve a density of 3.5gm/cc. The density for light concrete is 2.35 gm/cc. The compositions by atomic fractions are given in Table I.

Table I. Atomic Fractions

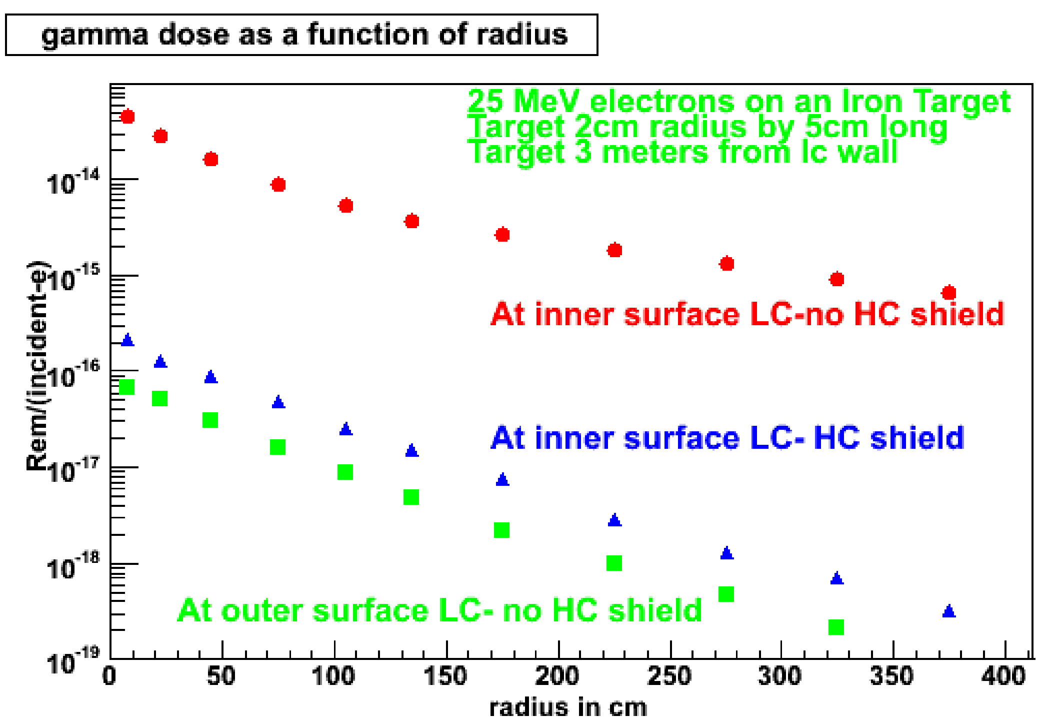
atom	Light concrete	Heavy concrete
H	0.135	0.107
O	0.6529	0.515
Si	0.1185	0.094
Al	0.0182	0.014
Ca	0.0754	0.060
Fe	0.0	0.21

The target used for the calculations was a steel cylinder with a radius of 2 cm and a length of 5 cm. Most materials close to the beam are similar in atomic number to iron so steel was a natural choice for the target material. The forward losses of electrons and photons typically have several inches of steel equivalent in their path due to the beampipe, quadrupoles, and dipoles. The sensitivity to the target geometry was examined and some results for the forward position (radius<15cm) on the inner surface of the light concrete shield wall are shown in Table 2. The dose at large distances can decrease as the target becomes thin and more of the electron energy is lost in the initial part of the concrete wall rather than the target. Although smaller targets can give higher radiation doses on the shield wall it was decided that the target parameters above were a reasonable approximation for the target mass.

Table 2. Photon Dose at R<15cm

Target Length (cm)	Target Radius (cm)	Rem per Incident electron
10	2	1.2E-14
5	2	4.4E-14
2.5	2	8.1E-14
1.5	2	1.1E-13
1.5	1	1.1E-13
1.5	0.5	1.1E-13
0.75	0.5	1.3E-13

The dose as a function of distance from the beam axis is shown in Figure 1. The data are averaged over radial bins ranging from 15cm to 50 cm in width. The red circles display the photon dose on the inner surface of the concrete wall. The green squares show the dose on the outside of the four feet of light concrete. The radial bin with R<15cm has the dose decrease by 0.0015 after 4 feet of light concrete. The blue triangles display the dose on the inner surface with the heavy concrete wall present. The dose for R<15 is reduced by 0.005. The application of concrete and steel TVLs would have given a reduction of 0.007 (see Ref. 1). The statistics in the simulation are not sufficient to extract the dose at the outer surface. The factor of 0.0015 from the light concrete can be used to estimate the dose for R<15cm on the outer surface to be 3.3E-19 rem/e.



The dose rate can be estimated assuming a rate of beam loss. A 50kW beam loss (0.926 mA) has an estimated dose rate of 3000 rem/hr (R<15cm) for the configuration without the inner heavy concrete wall. This result compares well with a thick target formula with concrete TVL's, which would estimate 6600 rem/hr (Ref. 1 with geometry differences taken into account). The addition of the two feet of heavy concrete reduces the maximum dose to 15 rem/hr for a 50 kW beam loss. Most situations have the source of forward radiation at greater distance from the shield wall and have a non-zero angles to the shielding. The routine losses are expected to be at least 1000 times lower than a 50 kW loss.

9.Conclusions

A simple estimate of the dose rate outside the ERL test area sidewall shielding is made incorporating a proposed two-foot thick inner heavy concrete wall. The estimate of 15 rem/hr for a 50 kW beam loss would be within guidelines with chipmunks distributed to detect large beam losses. Actual beam loss configurations are expected to have reduced radiation due to increased distance and angles relative to the shielding. In addition, a 50 kW localized beam loss is not expected to be possible.

References

D. Beavis Memorandum, "Simple Estimate of ERL Radiation", August 9, 2006.
D. B. Pelowitz,Ed. "MCNPX User's Manual, Version 2.5.0", April 2005; version 2.5f was used for these calculations

Dose Rate Estimates for ERL Penetrations

March 26, 2008
D. Beavis

Introduction

Dose estimates for the penetrations in the ERL facility are provided. The estimates use a combination of simple source terms and estimates of the attenuation of the radiation as it propagates through the opening. The estimates provided in this document are intended to be crude order of magnitude estimates. Conservative assumptions are usually used so that the estimates represent upper limits for the potential dose rates. The low-intensity commissioning process of the RF-gun, five-cell cavity, and transport of the low energy and high energy electron beams will be used to verify the source terms and radiation transport through the shielding and penetrations.

Figure I is a plan view of the shielded area of the facility. There are approximately 20 penetrations through the external shielding. Two of these penetrations are used for personnel and equipment access. Several of the penetrations are buss blocks containing several dozen small penetrations for access of utilities. Other penetrations are intended for electrical cables, cryogens, gas exhaust, laser beam, etc. The overall features are a superconducting RF gun, a five-cell superconducting energy recovery linac (ERL), low energy beam transport to the beam dump, and the 25 MeV electron ring. The side walls are composed of between four and eight feet of light concrete. The thin sections of wall are shadowed from the potential sources with inner shield walls located appropriately. The entire facility has a single layer of light concrete roof beams four feet thick, except for a transition region where the roof is two layers of roof beams. This transition region is where the 13 foot ceiling height in the center is reduced to 9 feet at both ends.

There are restrictions on access for the facility areas. Access into the machine area is prevented by dual interlocks when the machine is operational. This includes the operation of the electron beams, the RF-Gun and five-cell cavity. Personnel will not be allowed on the roof during operations. Personnel will not be allowed in the 1 megawatt power supply room during operations. A substantial area between the adjacent experimental building and the ERL shielding on the west side will be fenced and locked with personnel excluded during operations or with limited access.

The radiation sources are predominately x-rays and gamma rays. The 25 MeV electron beam is capable of generating neutrons. Only in conditions where substantial high-Z shielding materials have been used or where it takes many bounces for radiation to get through a penetration is it possible for the neutron dose rates to dominate the x-ray dose rates.

The shielding is evaluated for two types of exposures, chronic and fault conditions. As will be discussed below the dose rates during fault conditions are typically many orders of magnitude larger than that of the chronic (routine) conditions. The penetrations will not be considered for the chronic dose to personnel since the areas around the penetrations are typically not occupied and they can be posted for localized elevated dose rates. The penetrations are considered as an issue for dose to personnel during a fault condition.

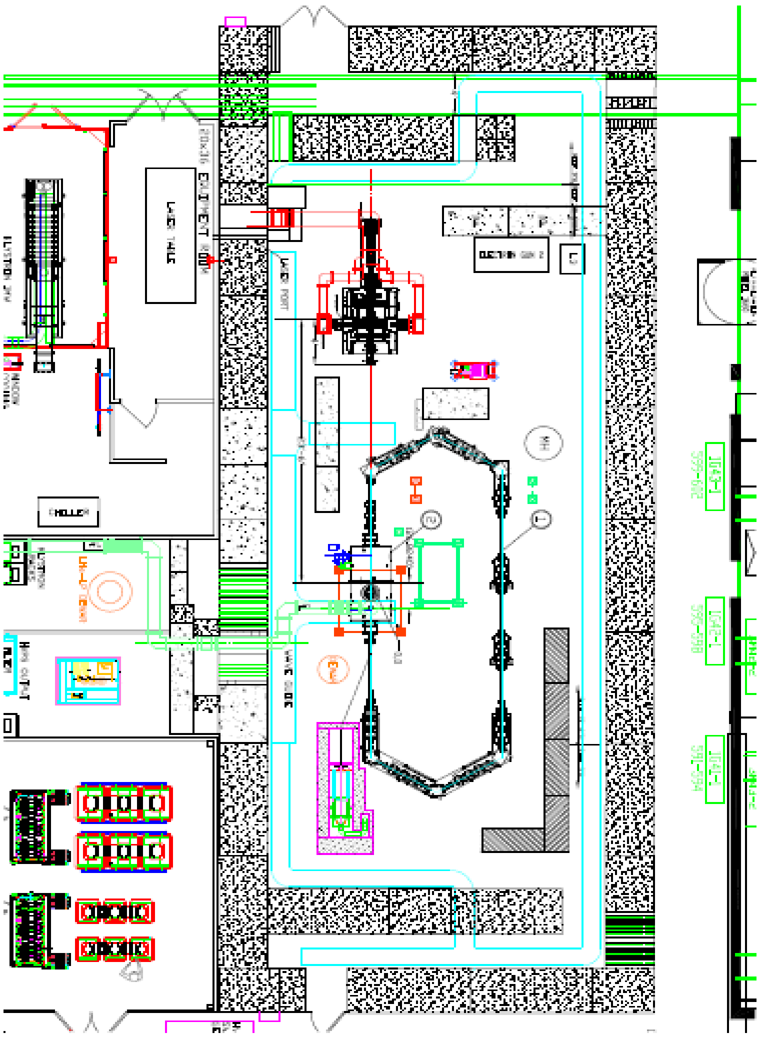


Figure I. Shielded ERL Area

All areas near the ERL shielding should be posted at least as a Radiation Area, TLD Required. Any unplanned exposure exceeding 100 mrem is a DOE reportable occurrence. This establishes an upper limit of exposure to personnel during an unexpected fault condition. Large dose rates caused by unusual operating conditions will be detected by radiation monitors (chipmunks) distributed around the area. These devices are coupled with the interlock system and will terminate the radiation in 1 to 9 seconds depending on the level of radiation at the detector. **This establishes an upper dose rate of between 40 and 360 rem/hr depending on the duration of the fault for areas that can be occupied by personnel.**

Radiation Source Terms

The four sources of radiation in the area are the RF-Gun, beam losses of the low-energy (E_k<3.5 MeV) electron beam, the five-cell cavity, and beam losses of the high-energy electron beam (E_k<25 MeV). Most of the calculations used in this note will use the source terms discussed in reference 1, which were based on formulas and figures from references sited in that note. In some cases more detailed calculations are used. The source terms used are conservative. The commissioning process will provide a check on the source terms and the effectiveness of the shielding.

The RF gun and the five-cell cavity can generate copious x-rays. No modeling has been conducted for the RF gun and the five-cell cavity in terms of the x-ray generation, but experience from other systems can be used for guidance. When these devices are commissioned, careful attention will be given to the measurement of their potential to create x-rays. The conditioning of the cavities will cause the largest x-ray generation from the cavities. The five cell cavity is expected to be able to absorb 100 to 1000 watts from electron emission before boiling too much helium and becoming normal. The voltage difference that the electrons cross will typically be less than the gradient of a single cavity, 5 MV. Only a few electrons would be accelerated across several cavities. It is assumed that **all the electrons are at 3.5 MeV with a maximum conditioning loss of 250 W**. It is expected that the **routine loss is less than 10 W** for the five cell cavities. **We will assume that the RF gun has the same limits**. The methods discussed in reference 1 can be used to estimate the 90-degree radiation, using thick target formulas. The expected dose rates for commissioning and routine operations are:

Cavity x-rays assuming 3.5 MeV

cavity	Conditioning (250W) rem/hr at 1m	Routine (10W) rem/hr at 1 m
Five-cell	2000	80
RF-gun	2000	80

The maximum kinetic energy of the x-ray gun is 3.5 MeV. It is expected that it will typically operate at a lower kinetic energy. The rule of thumb[2] for 0 degree radiation in this energy region is that it grows as the energy squared at fixed power. Therefore using 3.5 MeV represents a conservative figure.

3.5 MeV e- losses rad/(hr-kW)at 1 m

0 degrees	$4*10^4$
90 degrees	$8*10^3$

The source terms for electron losses at one meter for 25 MeV electrons are (an approximate value for 30 degrees has been added):

25 MeV e- losses rem/(hr-kW) at 1 m

angle	gamma	neutron
0 degrees	$8*10^5$	430
30	$8*10^4$	430
90 degrees	$8*10^3$	430

The dose rates for beam losses at 3.5 MeV and 25 MeV given above are based on high-Z thick target formulas or curves and are a conservative estimate. The radiation from actual losses can be up to a factor of 10 lower than the above estimates.

Reference 3 estimated the dose from a 25 MeV electron beam loss in the near zero degree direction to be 9000 rad/hr at 3 meters with 2 feet of heavy concrete between the source and the point of interest with a 50 kW loss. This will be used for locations where an inner shield wall (see Figure I) acts as a shadow for the 25 MeV beam losses.

The routine beam losses and maximum credible beam losses are needed to estimate the potential dose from chronic sources and for unusual conditions. The **maximum sustainable beam loss that the 5 cell cavity can support is 50 kW**, which is limited by the power supply. Many people believe that the **maximum local loss that can occur is between 10-100 W before the machine is damaged and shuts down**. The ERL will have machine protection devices to limit the losses to avoid equipment damage. However, no demonstrated mechanism to limit the beam loss has been demonstrated so a **50 kW limit is used for the 25 MeV electron beam**. The facility will have several chipmunks distributed at key locations to limit the duration of the beam faults. A 50 kW loss is probably appropriate to apply for short durations appropriate to the time required for the interlocks to stop the beam, which is typically 1-10 seconds depending on the dose rate at the chipmunk sensing the radiation. The 50 kW is considered conservative.
Routine losses are expected to be less than 10 W.

The **3.5 MeV beam has a power limit of 1 MW**. This power can be placed in the water cooled beam dump, which has local shielding. Again it is not expected that the machine can survive a large beam loss at any location, except the beam dump. The beam dump has a shielding criteria that it will represent less than a routine loss and is not considered for the penetration in this note. An **arbitrary maximum limit of 1 kW (10^{-3}) is assumed** without justification in this analysis. **A routine loss of 10 W (10^{-5}) or less is expected.** Any routine loss higher than this will be reviewed for the possible addition of local shielding.

Table I provides a summary of the source intensities used for fault conditions and routine operations. These are expected to be conservative and checked during the commissioning process.

Table I. Dose Rates for Routine and Maximum Losses

Condition	**Dose rate (rem/hr) at 1 meter for Max. sustainable loss**		**Dose rate (rem/hr) at 1 meter for Routine loss**	
	Gamma	Neutron	Gamma	Neutron
RF GUN	2000		80	
5-cell Cavity	2000		80	
3.5 MeV-0 deg.	$4*10^4$		$4*10^2$	
3.5 MeV-90 deg.	$8*10^3$		$8*10^1$	
25 MeV-0 deg.	$4*10^7$	$2.15*10^4$	$8*10^3$	4.3
25 MeV-30 deg.	$4*10^6$	$2.15*10^4$	$8*10^2$	4.3
25 MeV- 90 deg.	$4*10^5$	$2.15*10^4$	$8*10^1$	4.3
25 MeV-0 deg. 2ft HC at 3 meters from source	$9*10^3$		0.18	

The dose rate through a penetration is estimated by scaling the dose rate of Table I with 1/(r*r) to the entrance of the penetration and then applying an attenuation factor for the penetration. The attenuation for neutrons can be estimated using empirical formulas such as those presented in references 4 and 5. Typically the attenuation for gammas in multi-legged labyrinths is lower than neutrons, but the neutron formulas do not typically apply to gammas. For gammas, reflection coefficients are used for the surfaces of the labyrinths. This technique can also be applied for neutrons but is limited in applicability. Curves in Sullivan[4] are used for straight penetrations unless otherwise stated.

Some penetrations are shadowed by shielding. The entrance dose for the penetration has a component of radiation that arrived at the penetration by reflecting off surfaces to avoid the shadow shield. Another component of the entrance dose penetrates through the shadow shielding and then travels to the penetration. The TVLs from reference 1 and reference 8 are used[9] to calculate the attenuation of the radiation by the shield.

Laser penetration

The laser penetration is a straight hole through the shielding to allow for the transport of the laser beam to the RF gun. The penetration is 3 inches by 4 inches and is about one foot above the floor. It is located underneath the 1 MW wave guide shown in Figure 1. An enlargement of Fig I for this area is provided in Figure II. The arrows in Fig. II show potential sources for several penetrations. The 5-cell cavity is shadowed by the inner-shield wall and will not be considered as a source. Locations that represent the largest possible dose rates have been used for the analysis. The equivalent of two feet of heavy concrete will shadow the laser penetration from any radiation that could arrive directly from the potential sources. The two feet of heavy concrete provides attenuations from $1.5*10^{-2}$ to $3.2*10^{-4}$. Dose rates at the entrance to the laser port are given in the Table II below.

Table II: Laser port entrance Dose rates

Condition	**Distance (m)**	**Max. dose rate (rem/hr)**		**Routine Dose rate (rem/hr)**	
		Gamma	Neutron	gamma	Neutron
RF Gun	3.3	0.06		0.002	
3.5 MeV e	4.3	1.4		0.014	
25 MeV e-90 degree	7.3	25.5	3.9	0.005	0.0008
25 MeV e-30 degree	12	420	1.4	0.08	0.0003

The radiation can also enter the laser penetration from the side wall after one or more reflections. The details of the area are not sufficiently complete to evaluate the attenuation at this time. The design of the shielding will ensure that the exit dose rate for radiation that circumvents the shielding will be less than the dose rate for the punch through contribution.

The approximate value of the attenuation of this penetration is $5*10^{-3}$ based on figures 2.25, 2.26, and 2.27 of Sullivan. The exit dose rates are given in the table below.

Table III: Laser port exit Dose rates

Condition	**Distance (m)**	**Max. dose rate (mrem/hr)**		**Routine Dose rate (mrem/hr)**	
		Gamma	Neutron	gamma	Neutron
RF Gun	3.3	0.3		0.01	
3.5 MeV e	4.3	1.2		0.01	
25 MeV e-90 degree	7.3	128	20	0.03	0.004
25 MeV e-30 degree	12	2100	1.4	0.4	0.001

There are several comments that are worth noting. The highest gamma dose rate does not come from the same location as the highest neutron dose. These cannot be added since this would represent to beam losses at twice the maximum. Since one is looking for order of magnitude estimates it is not important to add these for a fault condition and the error will be smaller than the accuracy of the calculation. The routine dose rates are small and will not be presented throughout this note. The maximum dose rates can be scaled using Table I to obtain the routine/chronic dose rates. The chronic rates assume that the entire routine beam loss occurs at the worst possible location for the penetration being considered, which is an over estimate.

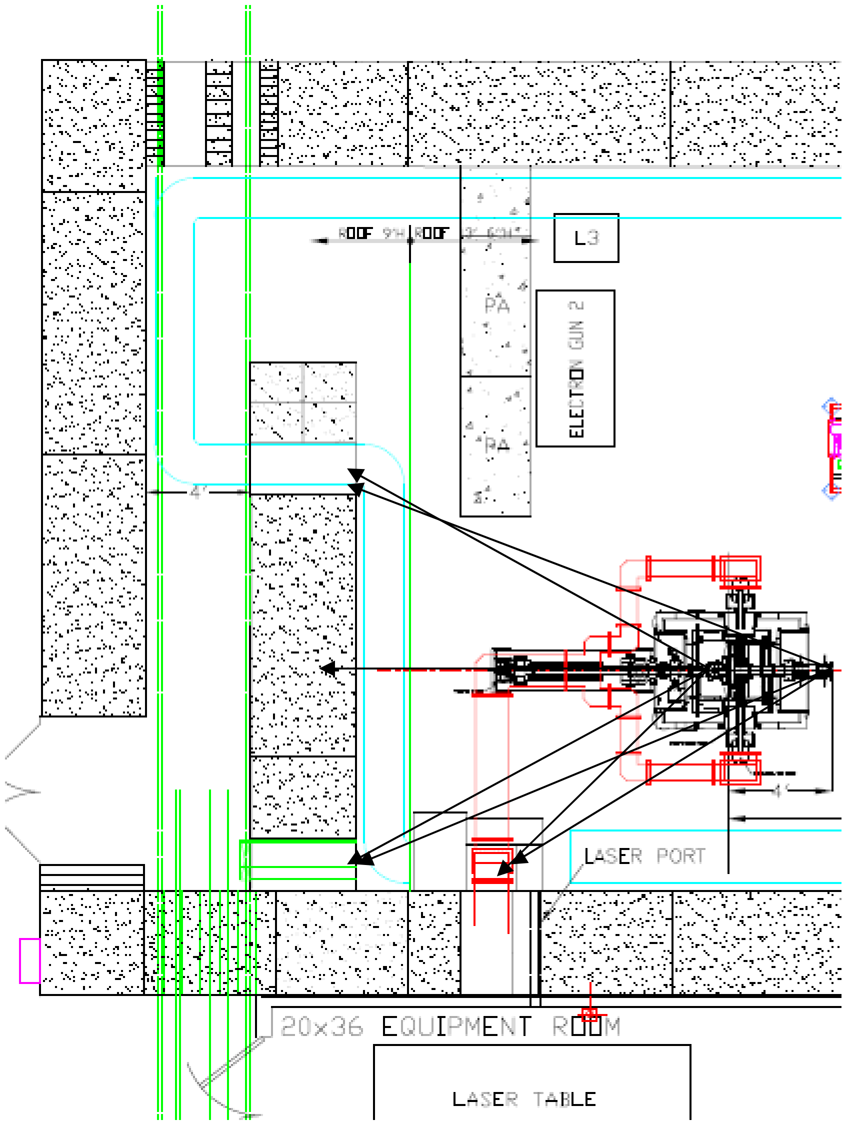


Figure II. Plan view of South section of ERL Area

I MW Waveguide Penetration

The penetration for the 1 MW waveguide is a two legged labyrinth. An elevation view is shown in Figure III. The cross sectional area of the first (second) leg is 2ftx2ft (1ftx2ft). The length of the first (second) leg is 2.9 ft (4 ft). The radiation has two pathways to get to the exit of the port.

Two-feet thick heavy concrete shadows the opening in the main concrete shield wall from the x-ray and neutron sources. The gamma radiation can penetrate the heavy concrete and shine into the second leg. The attenuation factors are the same as those used for the laser penetration. The distance to the source will be assumed to be the same as the laser port at lower elevation, which means the entrance dose rates for radiation "punching-through" the heavy concrete is the same as the laser port. An attenuation factor of 0.1 for the hole in the shielding is used from reference 4.

The exit dose rates for radiation punching through the heavy concrete are given in the Table IV below:

Table IV: 1 MW Waveguide Exit Dose Rates for punch-through

Condition	**Distance (m)**	**Max. dose rate (mrem/hr)**		**Routine Dose rate (rem/hr)**	
		Gamma	Neutron	gamma	Neutron
RF Gun	3.3	6		0.2	
3.5 MeV e	4.3	140		1.4	
25 MeV e-90 degree	7.3	2550	390	0.5	0.08
25 MeV e-30 degree	12	42,000	140	8	0.03

The contribution for the dose for neutrons propagating through the two-legged labyrinth can be estimated using the attenuation formulation of Goebel[5]. An approximate attenuation of $1.0*10^{-3}$ is obtained for the neutrons. The gamma attenuation is estimated using the reflection coefficients. An area for the first scatter of 20 ft^2 is used with a reflection coefficient of $3*10^{-3}$ and a distance of 5 feet. An area of $4ft^2$ is used for the second scatter along with a distance of 5 feet and a reflection coefficient of $3*10^{-2}$. A net attenuation of $1.2*10^{-5}$ is obtained for the gammas.

Table V: 1 MW Waveguide Exit Dose Rates –as Labyrinth

Condition	**Distance (m)**	**Max. dose rate (mrem/hr)**		**Routine Dose rate (mrem/hr)**	
		Gamma	Neutron	gamma	Neutron
RF Gun	3.3	2			
3.5 MeV e	4.3	5		0.05	
25 MeV e-90 degree	7.3	90	400	0.02	0.08
25 MeV e-30 degree	12	330	149	0.07	0.03

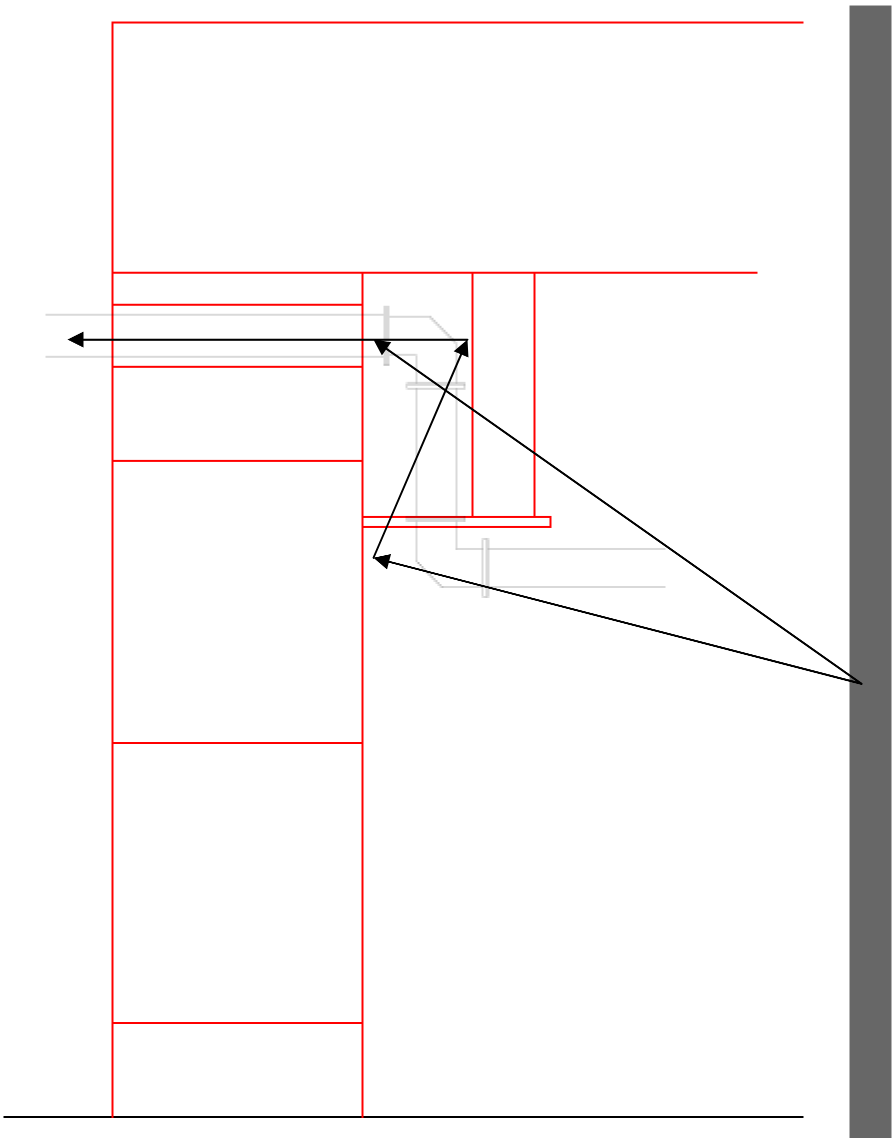


Figure III. 1 Megawatt Waveguide Penetration

Cryo Ports

Five 1ft by 1 ft penetrations exist at the top of the back wall for cryogenics. These ports are straight penetrations. The present plan is to close several of the port with packing block. They will be available in the future for use as utility ports if necessary. One port already has vacuum jacketed cryogenics piping in it. This pipe extends nearly to the adjacent building. Another port will be used for a vent, which will have an elbow immediately outside the shield wall. One port may be used for a few utility pipes and will be packed with shielding. Table VI shows the dose rates at exit of the ports assuming no packing, no shadow shields, and no credit for the shielding provided by the pipes:

Table VI: Cryo Ports Exit Dose Rates

Condition	**Distance (m)**	**Max. dose rate (mrem/hr)**		**Routine Dose rate (mrem/hr)**	
		Gamma	Neutron	gamma	Neutron
RF Gun	6.2	21,000 (470)		840 (19)	
5-cell cavity	6.2	21,000 (470)		840 (19)	
3.5 MeV e	6.2	84,000 (1900)		840 (19)	
25 MeV e-90 degree	3.2	3,800,000 (84,000)	200,000 (4400)	760 (17)	40 (0.9)
25 MeV e-30 degree	5.3	2,800,000 (63,000)	73,000 (160)	560 (12)	15 (0.3)

The worst cases were used for the estimates. The area between the shield wall and the EEBA building is intended to be a fenced area to keep personnel away from these ports. The edge of the building is seven feet away. If we assume the radiation exiting the hole is uniformly diffused over a cone of half-angle of 45 degrees then the radiation levels in the adjacent building will be a factor of 45 lower. **The numbers in parenthesis are the dose rates in the adjacent building** directly across from the port at a height of 12.5 feet.

The ports shall be modified to reduce the fault dose rates by a factor of at least 10. For a port using a steel shielding plate this requires 4 inches (10cm) of steel. For ports that are made smaller the area should be at least a factor of 9 smaller to reduce the radiation more than a factor of 10.

North Personnel Labyrinth

There are several aspects of this area that need to be considered. Figure IV shows a detail of the north labyrinth area. The north-west corner of the labyrinth has a buss block with penetrations to the outside. There is a cable port that acts as a short cut to the labyrinth about 10 feet from the gate. In addition the radiation that penetrates through the inner concrete wall then can enter the labyrinth close to the gate. In the final design the dump shielding shadows the gate entrance from the ring losses. Presently there is a two-foot thick iron shield in that location. Finally, the labyrinth can be treated as a four-legged labyrinth.

Direct radiation is shadowed from striking the buss block area. The near zero degree gamma radiation can arrive at the buss block area with two reflections. Using reflection coefficients the gamma dose would be expected to be reduced about $3*10^{-5}$ from that of the source at a meter. Using the penetration curves from Sullivan one would expect a reduction of another $3*10^{-3}$ for the radiation exiting the port. This gives a net reduction of 10^{-7}. **A beam loss of 50 kW at 25 MeV produces a gamma dose rate of 4 rem/hr**. The routine dose rate is expected to be less than 1 mrem/hr. This is not expected to be an issue. A chipmunk should limit the losses well below 50 kW anywhere in the 25 MeV ring and if desired the area outside the buss block can be part of the exclusion area needed for the cryogenics penetrations that have been discussed earlier. **The neutron dose rate exiting the buss blocks is estimated to be 100 mrem/hr for a 50 kW beam loss close to the labyrinth opening**.

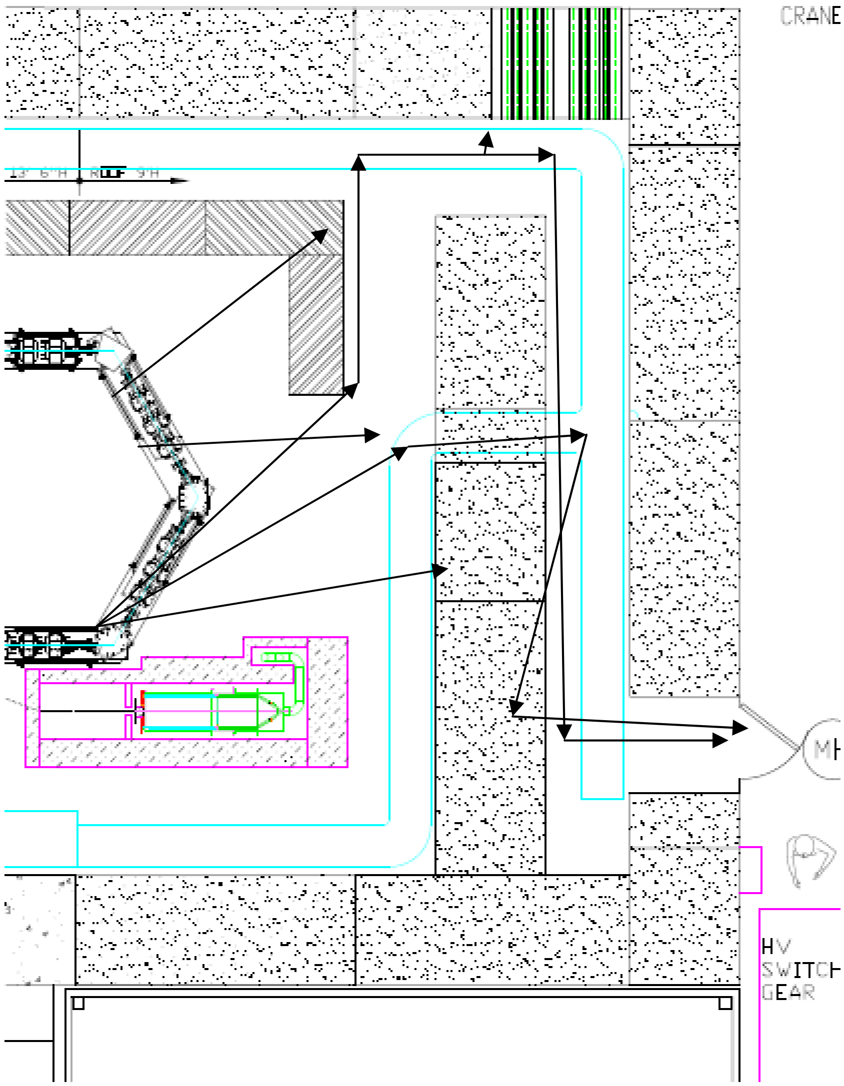


Figure IV. The Area of the North Personnel labyrinth

The radiation can also get to the ports in the buss block by penetrating the inner two-foot thick iron shield wall. The shield wall will provide an attenuation of $3*10^{-6}$ for forward gammas, ignoring the additional reduction due to the angle through the shield. The gamma dose is negligible when the port attenuation is taken into account. The reduction for neutrons, Ignoring the angle through the steel, is $9.3*10^{-3}$. **The neutron-dose rate exiting the port would be 25 mrem/hr from this contribution**. In reality, the additional distance through the steel would reduce the neutrons another factor of ten.

The north labyrinth can be treated as a four-legged labyrinth using the formulation of reference 5 to obtain the dose rate for neutrons at the gate. The attenuation for neutrons is 10^{-5}. The neutron entrance dose rate into the labyrinth is 75 rem/hr when a 50 kW beam loss occurs near the entrance. The **exit neutron dose rate at the gate is less than 1 mrem/hr for the 50 kW loss**. The routine loss is negligible.

The gamma and x-rays traveling through the labyrinth require at least 5 bounces to get to the exit gate. The maximum reflection coefficient[6] for 0.2 to 10 MeV gammas is .04. Using this fixed value for 5 bounces an attenuation of 10^{-7} is obtained without taking credit for the reduction due to distance. The zero degree gamma dose is very peaked in the forward direction. A crude estimate of $8.2*10^5$ rad/hr is used for the entrance dose averaged over the opening of the labyrinth. **The 50 kW beam loss produces an exit gamma dose of 80 mrem/hr at the gate.**

The zero-degree radiation can penetrate the shield wall to the west of the gate. The radiation would require two bounces to get to the gate. The peak dose rate penetrating the 4 feet of light concrete has about 1350 rad/hour for gammas 50 cm off axis of the zero beam[7]. Using an effective area of 28 ft^2 and the reflection coefficients a **gamma dose rate at the gate of 28 mrem/hr is obtained for a 25 MeV beam loss of 50kW.**

The neutrons penetrating the inner shield wall can be calculated using TVLs. A neutron dose rate of 2.7 rem/hr would exist at the light concrete wall. The transport to the gate can be estimated as a two legged labyrinth with an attenuation of $2*10^{-2}$. An additional factor for the source size to the width of the isle, about a factor of four, should be incorporated. This results in a **potential neutron dose rate at the gate of 250 mrem/hr neutrons for a 50 kW beam loss.**

Cable tray that penetrates the wall about 8 feet from the gate will allow neutrons and gammas to get to the gate without going through or around the inner shield. The dose is calculated at the exit the cable port and then transported using the two-legged labyrinth formula for neutrons and 2 bounces for gammas. **The dose rates at the gate are 1.8 rem/hr neutrons and 260 mrem/hr gamma for a 50 kW beam loss.**

The various paths of radiation for the same loss location to the gate are additive. The contribution of the cable tray penetration through the inner shield wall contributes the largest portion of the dose.

South Personnel Labyrinth

The south personnel and equipment labyrinth has pathways for radiation to reach the gate as well as penetrations from locations in the labyrinth to the outside. These will be examined similar to the north personnel labyrinth.

The labyrinth can be viewed as a four legged labyrinth. For neutrons the attenuation of the labyrinth is $3*10^{-5}$. The closest neutron source from a scraping loss produces a neutron-entrance dose of 342 rem. **The expected neutron-exit dose is 10 mrem/hr for a 50 kW beam loss.**

Photons can strike the shielding wall and then be reflected into the labyrinth. It takes a minimum or four bounces for the photons to reach the gates. The photon reduction is of the order of 10^{-8} and even for a 50 kW beam loss the dose rates at the gate are well less than 1 mrem/hr. The maximum loss of the 3.5 MeV beam would create a few micro-rem/hr at the gate.

Photons and neutrons can punch through the wall behind L3 and reduce the effectiveness of the labyrinth. Using the results of reference 2 the photon dose at the light concrete is 336 rem/hr for a 50 kW beam loss. Two bounces are required to get the photons to the gate. The **photon dose rate at the gate is estimated to be 200 mrem/hr for a 50 kW beam loss.**

For neutrons the shield wall behind L3 was treated as heavy concrete with an attenuation factor of 45gm/cm^2. The neutron dose rate at the light concrete wall is 6 rem/hr. Using a labyrinth formula this will produce a few mrem/hr of neutrons at the gate for a 50kW beam loss.

Photons can travel over the shield wall near L3 and strike the roof transition. With two reflections the photons can be at the light concrete wall. The estimated dose rate via this path is **235 rem/hr at the light concrete wall**. This is similar to the number reached above and is additive. The cable tray can allow some neutrons to get to the light concrete with only one bounce. The estimated dose rate is 70 rem/hr at the light concrete wall. These contribute to the **photon-dose rate at the gate for a total of 400 mrem/hr.**

Neutrons can take a similar path and are expected to produce a few tens of mrem/hr at the gate.

Both neutrons and gammas rays can penetrate the concrete wall opposite the gate and then shine on the gate. The Table VII below lists the results of the dose rate estimates:

Table VII: Radiation Penetrating the Shield Wall Opposite the Gate

source	Dose rate mrem/hr Fault (routine)
RF-gun	1.8
Gamma-3.5 MeV e	4.5 (0.5)
Gamma-25 MeV e; 90 degree	1,900 (0.4)
Gamma-25 MeV e; 30 degree	49,000 (10)
Neutron-25 MeV e	160 (0.03)

A shield block could be placed in the center of the e-ring to shadow this wall from the forward angle radiation and substantially reduce the potential dose. Since the results are conservative, it might be desired to wait for commissions and see if this area is an issue for operations.

The cable port opposite the gate is approximately 7 inches by 24 inches. It is shadowed with 24 inches of heavy concrete used to form the labyrinth for the 1 MW waveguide. The TVLs for the various particles and energies were used to reduce the radiation at the port entrance. An attenuation factor of 0.1 was used for the penetration. The dose rates at the gate are substantially smaller than the dose rate at the exit of the penetration. A factor of 0.1 was used and expected to be conservative. The ratio of the gate area to the cable port area is more than a factor of 50. The estimated dose rates at the gate are given in Table VIII below:

Table VIII: Radiation at the Gate from Nearby Cable Port

source	Dose rate mrem/hr Fault (routine)
RF-gun	0.4
Gamma-3.5 MeV e	0.9 (0.01)
Gamma-25 MeV e; 90 degree	960 (0.2)
Gamma-25 MeV e; 30 degree	2400 (0.5)
Neutron-25 MeV e	33 (0.007)

The cable port 10 feet from the gate is shadowed from all sources except the RF-gun and perhaps the 3.5 MeV electron losses near the RF-gun. X-rays of the level 34 rem/hr and 135 rem/hr can exit the cable port for the RF-gun and electron beam losses respectively. After two reflections these can contribute 1.6 mrem/hr (RF-gun) and 2.3 mrem/hr (3.5 MeV beam loss).

The south labyrinth has several penetrations that allow radiation to escape the shielding. There are two cable way penetrations on the west end of the labyrinth (see Fig. II). The larger hole is 11 inches by 17 inches and the smaller is 6 inches by 12 inches. Dose rate estimates for photons near the adjacent light concrete wall was previously estimated to total 600 rem/hr for a 50 kW beam loss at 25 MeV. An area of the wall (approx. 1ft by 8 ft) can shine out the hole with one bounce off the concrete wall. This would give an estimated 5 rem/hr at the exit of the hole. The 600 rem/hr also shines on the opening of the hole and will produce approximately 60 rem/hr at the exit. The numbers will be smaller for the other port. **A combination of access controls and shadow shielding are required to reduce the levels to acceptable levels**.

The photons can bounce into the trench and exit the shield wall on the west side. The 600 rem/hr would produce 6 rem/hr outside the shielding wall. **It is recommended that the trench be blocked as much as possible to reduce this dose.**

The photons can also bounce off the light concrete wall and exit the trench on the east side or through the buss block on the east side. The trench is estimated to have a photon dose rate of 2 rem/hr. The buss block holes would have a lower dose rate. **Again it is recommended that the trench be blocked as much as possible.**

ODH Port on the Roof

The roof over the beam dump and ring has a ventilation port. This port represents a large opening with dimensions of 2 feet by 4 feet. The port is constructed as a 3-legged labyrinth with a block shadowing the initial opening. The ODH port labyrinth is shown in Figure V.

The dose rate exiting the penetration should be compared to what is expected to penetrate directly through the four feet thick light concrete roof. Using the TVLs for light concrete we expect:

Table IX: Radiation Through 4 foot light concrete Roof

source	Dose rate through roof at max. fault condition (mrem/hr)
3.5 MeV RF Gun or Five-cell cavity	5
3.5 MeV e beam-photons	22
25 MeV e beam-photons	18,000
25 MeV e beam-neutrons	1,000

The neutron and gamma radiation can penetrate the 4 foot light concrete and then shine to the end of the labyrinth. These dose rates are lower than the adjacent roof since the shielding is the same thickness but the distance is greater and therefore is less than the adjacent roof given in Table IX.

The area under the air handling unit has a shielding path that is about 80 gm/cm^2 thinner. This would make the radiation levels 10 times higher than the adjacent roof if the extra distance is ignored. The dose rates would be of the order of **10 rem/hr neutron and 180 rem/hr gamma**. This area is blocked by the air handling unit.

For neutrons the port can be treated as a three-legged labyrinth. The attenuation is approximately 10^{-3}. The **neutron dose rate for a 50 kW beam loss is 4 rem/hr**.

It requires a minimum of three bounces for gamma rays to exit the ODH port. Similar to above a fixed reflection coefficient of 0.04 for each bounce will be used. Ignoring distances and areas a **gamma dose rate of 10 rem/hr** is estimated.

Holes on Roof Created by Lifting Fixtures

There are four holes on the roof formed by the roof elevation transition and the lifting fixture for the roof beams. These holes are 4 feet long and are approximately 0.4 ft^2 in area. Personnel are excluded from the roof when the sources or machine operating.

Using the figures in Sullivan (figures 2.24-2.27) an attenuation of $5*10^{-2}$ will be used for both neutrons and photons. The exit will be blocked with the equivalent of 1 foot of light concrete.

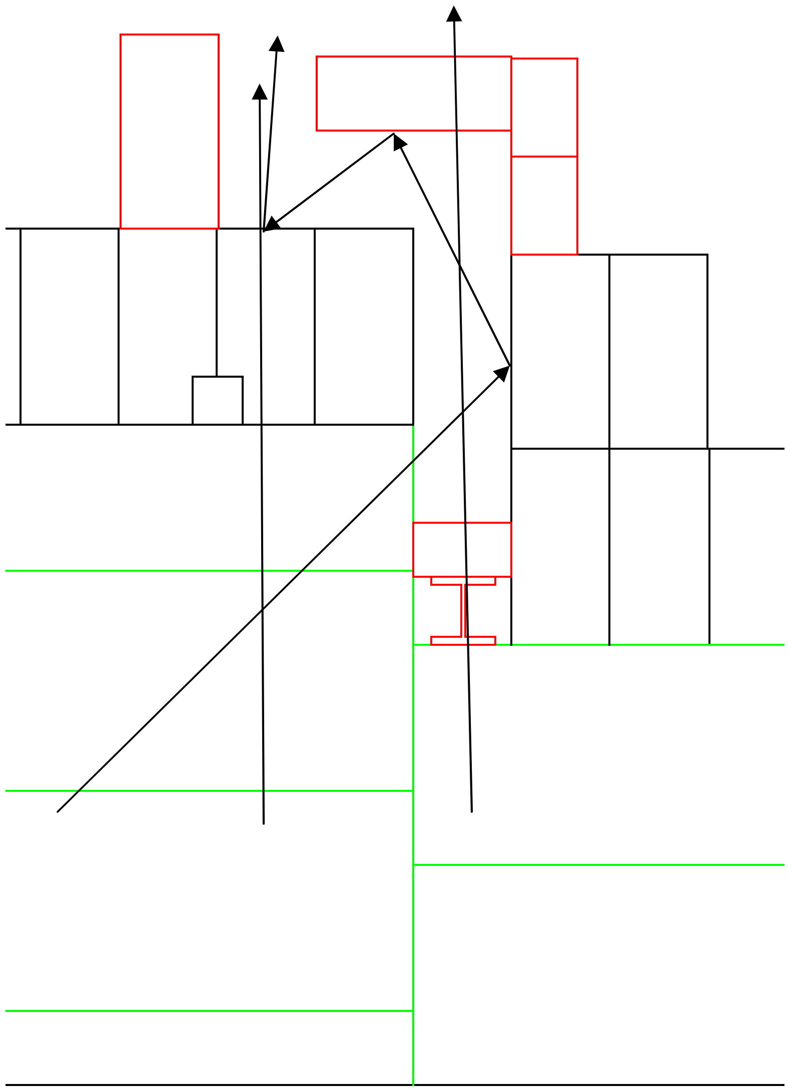


Figure V. Elevation View of ODH Port

This provides a reduction of 0.068 for low energy gammas and a reduction of 0.13 for high energy gammas and neutrons. The following results were obtained for worst case examples for the various sources and the holes:

Table X: Dose Rates at lifting Fixture Holes

Source	***Dose rate mrem/hr***	***Loss***
RF gun	520 (1)	2000 rad/hr at 1 m
3.5 MeV e	1,100 (2)	1 kW
25 MeV e; neutrons	3,800 (8)	50 kW
25 MeV e; gammas at 30 deg.	700,000 (1,400)	50 kW

The edge of the shield wall is at least eight feet away. The number in parenthesis is the expected dose rate at the shielding edge assuming that the radiation is uniformly distributed in a cone with a 45 degree opening half-angle.

Summary

Table XI provides a summary of the worst dose rates at each area for the gamma rays and neutrons. The maximum neutrons can come from a different source location than the gamma rays. In all cases, the maximum gamma dose rates are from the 25 MeV electron beam losses.

XI: Maximum Penetration Dose Rates

penetration	Max. Gamma Dose rate (mrem/hr)	Max. neutron Dose Rate (mrem/hr)
Laser port	2,100	20
1 MW Waveguide	42,000	400
Cryo Ports (5)	8,400 [1]	2000 [1]
North Gate	260	1800
North Labyrinth Buss Block	4,000 [2]	100
South Gate	49,000 [3]	160
Port in South Labyrinth (2)	60,000 [4]	600 [5]
West Trench	6,000	100 [5]
East Trench	2,000	1,600 [5]
South labyrinth buss block	100	300 [5]
ODH Vent	10,000 [6]	4,000 [6]
Lifting Fixture holes (4)	1,400 [7]	8 [7]
50 kW waveguide	28,000 [8]	1,000 [8]

Comments:

[1] Assumes that steel has been used to reduce the gamma rays by a factor of 10.
[2] This is directly outside the buss block. This may be in a fenced area.
[3] A shield block in the ring center would substantially reduce this number, if desired.
[4] At port exit which may be in a fenced area. Port may be packed in the future. This value is for the port with the highest dose rate of the two ports.
[5] Not presented in text.
[6] This is on the roof and is not allowed to have personnel.
[7] Evaluated at the edge of the shielding and not on the roof.
[8] The penetrations for the cables ports, water pipes and the 50 kW waveguide are presented in another note (see reference 10). The dose rates presented here are at a height of 12 feet above the floor.

All the dose rates in Table XI are sufficiently low that with appropriately placed radiation monitors to terminate the beam on large beam losses the exposure to personnel will be less than 100 mrem in a fault. Several of the larger dose rates can be reduced and some suggestions have been made in the text. Many of the large dose rate estimates are most likely very conservative and not expected to occur. The initial commissioning process at low currents will provide a check of the estimates.

The initial commissioning of the RF gun and five-cell cavity will provide an opportunity to examine the penetrations for x-rays at a much reduced level. One or two chipmunks are planned to be placed inside the shielded area to verify the source terms for the RF gun and five-cell cavity. The proposed test to run low intensity 25 MeV electrons into a flange at the north side before the ring is operational will also provide an early check on the shielding and penetrations.

There have been several suggested or assumptions to the shielding in this note. Table XII lists some of them for consideration:

XII: Suggestions for Penetrations

Area	**suggestion**
I MW Penetration	Check shielding meets assumptions
Laser penetration	Check shield meets assumptions
Cryo ports	Check shielding is added
Outside adjacent area to shielding	Define as radiation area
West side of shielding	Fence and lock when machine operational
South labyrinth penetrations on west side	Consider enclosing in locked area and adding shielding
Roof	Examine Roof access is properly prevented
Trench under shielding	Add some shielding to reduce dose rate and prevent access
South Gate	Consider block in center of ring to block forward radiation
Chipmunks-radiation monitors	Consider chipmunk locations to terminate large losses

References

1) D. Beavis," Simple Estimates of ERL radiation", August 9, 2008.
2) W.P. Swanson, Radiological Safety Aspects of the Operation of Electron Linear Accelerators, Technical Report Series No. 188, IAEA, Vienna, 1979.
3) D. Beavis, "The effectiveness of a two-foot Thick Inner Concrete Wall", Dec. 11, 2006. See figure 1 of the note.
4) A.H. Sullivan, A guide to radiation Protection and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear technology Publishing, 1992. See figures 2.25, 2.26, and 2.27.
5) K. Goebel et. al., "Evaluating Dose Rates Due to neutron leakage Through the Access Tunnels of the SPS", CERN LABII-RA Note/75-10(1975).
6) NCRP Report No. 144, Radiation protection for Particle Accelerator Facilities, NCRP 2003. See figure 4.12
7) See reference 3 and the figure for the MCNPX calculation.
8) P.K. Job and W.R. Casey," Preliminary Radiological Considerations for the Design and Operation of NSLS II Storage Ring and Booster Synchrotron", NSLS II Technical Note No. 13, July 25, 06.

9) The attenuation lengths for ion and heavy concrete given in reference 8 have been converted to TVLs.
10) D. Beavis, "Estimate of the Radiation Exiting Penetrations for the ERL 50 kW Waveguide, Cable Buss Block, and Water Pipes", Dec. 6, 2006.

APPENDIX 2

ODH Calculations

Collider-Accelerator Department

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managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: January 8, 2008 (Revised 6/16/08)

To: E. Lessard

From: R. C. Karol

Subject: ERL Oxygen Deficiency Hazard (ODH) Calculations

Purpose

To compute the appropriate ODH class for the ERL Cave in B912 and the ERL helium recovery building located just north of B912. Oxygen deficiency can be caused by a leak of cold helium or nitrogen fluid present in these buildings.

Summary and Conclusions

The goal of this calculation was to determine the Oxygen Deficiency Hazard (ODH) risk for the ERL Cave in B912 and the ERL helium recovery building located just north of B912 by computing the fatality rate for a major cryogenic fluid release. A spectrum of events may cause an oxygen deficiency. A major cryogenic system failure has been chosen to bound the consequences of all credible failures in the ERL Cave and the ERL helium recovery building as shown below. Spill rates are assumed to remain constant throughout the release. In addition, a catastrophic failure of a 500L cryogenic Dewar in the ERL Cave was examined.

Building	Free Volume	Bounding Cryogenic Leak Location	Spill Rate (SCFM) [Reference 1]	ODH Exhaust Fan Capacity (SCFM)
ERL Cave in B912	20,000 ft^3	Failure of 1-inch copper LN2 transfer line	3275	13,750
ERL Helium Recovery Building	9500 ft^3	Rupture of Kinney vacuum pump helium discharge line	1150	4,850

It is concluded that the ERL Cave and the ERL helium recovery building be classified as ODH 0 areas.

Applicable Criteria

The method and criteria in the BNL ODH Subject Area [2] was used to determine the ODH class for each ERL building.

ODH Model Description

The Fermi Model is a prescribed method to determine the necessary level of hazard control for a building having the potential for oxygen deficiency. The fatality rate in the model is the product of two numbers. One quantity is the probability per hour of an event causing an oxygen deficiency. The other quantity is found by estimating the minimum oxygen concentration during the transient, assuming instantaneous mixing of the air and inert gas in the building volume, and is represented by a factor between 0 and 1 (see Figure 1). The computed fatality rate is then used to define the ODH class necessary to protect personnel.

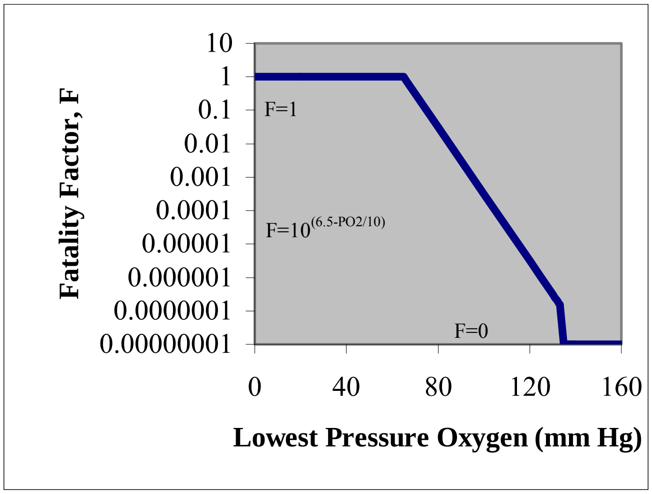
The Oxygen Deficiency Hazard fatality rate is defined as:

$$\Phi = PF$$

where Φ = the ODH fatality rate per hour
P = the expected rate of the event per hour, i.e. initiator frequency
F = the fatality factor for the event (Figure 1)

The value of P, the initiator frequency, is determined by using actual equipment failure rate data taken from the BNL SBMS subject area.

Figure 1. Graph of the Fatality Factor (logarithmic scale) versus the Computed Oxygen Partial Pressure.



The value of the fatality factor, F, is the probability that a fatality will result if the inert gas release occurs. Figure 1 from the SBMS defines the relationship between the value of F and the computed oxygen partial pressure. The partial pressure is found by multiplying the mole fraction of oxygen in the building atmosphere by 760 mmHg. If the oxygen concentration is greater than 18% (~137 mmHg), then the value of F is defined to be zero. That is, all exposures above 18% are defined to be safe and do not contribute to fatality. If the oxygen concentration is 18%, then the value of F is defined to be 10^{-7}. At decreasing concentrations the value of F increases until, at some point, the probability of fatality becomes unity. That point is defined to be 8.8% (~67 mmHg) oxygen in the Fermi model, the concentration at which one minute of consciousness is expected.

The value of Φ, the fatality rate, is then used to determine the ODH class of the building as follows:

ODH Class	Fatality Rate (per hour)
NA	$<10^{-9}$
0	$\geq 10^{-9}$ but $<10^{-7}$
1	$\geq 10^{-7}$ but $<10^{-5}$
2	$\geq 10^{-5}$ but $<10^{-3}$
3	$\geq 10^{-3}$ but $<10^{-1}$
4	$\geq 10^{-1}$

The oxygen concentration in the building during a release of a gas is approximated by solving the following differential equations:

(a) If the exhaust fan is on and the spill rate of inert gas (R) is less than the exhaust fan capacity (Q):

$$V\frac{dC}{dt} = 0.21\,(Q - R) - QC$$

Where

V = building volume (ft^3)
C = oxygen concentration (mole fraction)
t = time (minutes)
Q = exhaust fan(s) flow rate (CFM)
R = inert gas spill rate into building (CFM)

Solving results in the following equation:

$$C(t) = 0.21 [1 - R/Q(1-\exp(-Qt/R)]$$

(b) If the exhaust fan is off or if the inert gas spill rate (R) is greater than the exhaust fan capacity (Q):

$$V\frac{dC}{dt} = -RC$$

Solving results in the following equation:

$$C(t) = 0.21 \exp(-Rt/V)$$

Assumptions

1. Building volumes were measured with appropriate corrections made for determining the free volume.

2. The ERL Cave exhaust fan starts 30 seconds after the cave oxygen concentration sensors fall to 18% and has a capacity of 13,750 CFM. This exhaust fan capacity is chosen to ensure that the oxygen concentration in the cave never falls below 16%.

3. The ERL helium recovery building currently has no exhaust fan but has oxygen sensors which alarm at 18% oxygen concentration. An alternative is examined with an exhaust fan capacity of 4,850 CFM to ensure that the oxygen concentration never falls below 16%. The fan is assumed to start 30 seconds after the oxygen sensor trips at 18%.

4. The helium and nitrogen spill rates, assumed to remain constant, were obtained from Reference 1.

5. Outside air drawn into the ERL Cave has a 21% oxygen concentration.

6. As per the SBMS model, the oxygen concentration in the building is found by assuming instantaneous mixing of the air and cryogenic gas in the building volume.

Detailed Calculation and Analyses

1. ERL Cave ODH Calculation:

In order to simplify the calculation for the ERL Cave by avoiding a detailed analysis of the cryogenic system failure rates, the following was done:

1) Using the worst case cryogenic fluid spill rate [1], the time for the cave oxygen concentration to fall from 21% to 18% was determined using:

$$t = -\ln(0.18/0.21)\ V/R$$

where:
V = the ERL cave free volume, 20,000 ft^3
R = the maximum spill rate of nitrogen into the ERL cave, 3275 CFM

This results in a time of 0.94 minutes.

2) Assuming that it takes 30 seconds from the time of oxygen sensor trip until the ODH exhaust fan is at full capacity, the fan will be exhausting 1.44 minutes after spill initiation.

3) With t = 1.44 minutes, the oxygen concentration drops to a 16.6% just as the exhaust fan reaches full capacity of 13,750 CFM. This fan capacity ensures that the oxygen never falls below the steady state value of 16%.

4) Using this minimum oxygen concentration results in a partial pressure of 122 mmHg and a Fatality Factor, F, of 2.2×10^{-6}.

5) Next the initiator frequency, P, which results in a Fatality Rate, Φ of $<10^{-7}$ is found. A Fatality Rate of $<10^{-7}$ corresponds to an ODH 0 classification.

$$P = \Phi/F$$

Solving yields an allowable initiator frequency of P = 0.045 per hr to maintain an ODH 0 classification. This means that this major LN2 leak into the ERL cave, other pressure boundary failures with lower spill rates and human error resulting in a release of inert gas in the ERL cave could occur every 22 hours and still allow the cave to be classified as an ODH 0 area.

6) This initiator frequency is obviously unrealistically high compared to a credible frequency. Thus, controlling the ERL Cave as an ODH 0 area is acceptable and appropriate.

Finally, a catastrophic failure of a 500L He Dewar in the ERL Cave is examined to verify that ODH 0 is appropriate for this failure. The expansion ratio for helium from liquid helium at atmospheric pressure to room temperature helium gas at 70F is 754 [3]. Thus the released helium is 13,312 ft^3. Assuming perfect mixing of this release into the 20,000 ft^3 cave volume and ignoring any beneficial effects of the ODH exhaust fan, results in an oxygen concentration of 10.8%. The fatality factor at 10.8% oxygen is 1.96×10^{-2}. The probability of a Dewar rupture is 10^{-6} per hour [2], thus the Fatality Rate is 1.96×10^{-8} per hour. This is $<10^{-7}$ per hour so the designation of ODH 0 for the cave remains acceptable.

2. ERL Helium Recovery Building ODH Calculation:

The ERL helium recovery building ODH classification is first examined by finding the time for the oxygen concentration to fall to a level that would cause the room to exceed an ODH 0 classification without ant ODH exhaust fan. It is conservatively assumed that the initiating frequency for this event is once a year or 1.14×10^{-4} per hour. The assumed failure rate is very conservative since SBMS lists pipe-section rupture frequencies as ranging from 10^{-8} to 10^{-10} per hour. The once per year failure rate accounts for a burn-in period when ERL is first started up and prevents having to do a detailed failure rate study of the systems in the helium recover building.

1) Using the worst case cryogenic fluid spill rate [1], the time for the helium recovery building oxygen concentration to fall from 21% to 18% was determined using:

$$t = -\ln (0.18/0.21) V/R$$

Where:
V = the ERL helium recovery building volume, 9500 ft^3
R = the maximum spill rate of helium into the ERL recovery building, 1150 CFM

This results in a time of 1.3 minutes.

2) Conservatively assuming that the initiator frequency, $P = 1.14 \times 10^{-4}$ per hour means that F must equal 8.77×10^{-4} to have an ODH 1 classification.

3) If $F = 8.77 \times 10^{-4}$, then the corresponding oxygen concentration is found using:

$$F = 10^{(6.5-PO2/10)}$$
$$C = PO2/760\ (100)\ \%\ \text{oxygen}$$

Solving yields PO2 = 95.6 mmHg and C = 12.6% oxygen.

4) The time from the start of the accident to reach 12.6% oxygen is found to be 4.2 minutes.

5) Thus with the restraint to maintain the room posted as ODH 0, there is only 2.9 minutes to evacuate the building after the ODH alarm sounds. This may be

insufficient time to evacuate. The building has 2 doors and a footprint of 41' x 24' with three large equipment skids in the room.

As an alternative, an ODH exhaust fan having a capacity of 4,850 CFM is assumed. This alternative is necessary because the above scenario results in a low oxygen concentration and depends on a fairly rapid response time for the building occupants to escape. An exhaust fan capacity of 4,850 CFM was chosen to ensure that the oxygen concentration never falls below 16%.

1) From step 1 above it takes 1.3 minutes to trip the oxygen senor when the oxygen concentration falls to 18%.

2) Assuming that it takes 30 seconds from the time of oxygen sensor trip until the ODH exhaust fan is at full capacity, the fan will be exhausting 1.8 minutes after spill initiation.

3) With t = 1.8 minutes, the oxygen concentration drops to a 16.9% just as the exhaust fan reaches full capacity of 4,850 CFM. The oxygen concentration then slowly falls to a steady state value of 16%.

4) Using this minimum oxygen concentration results in a partial pressure of 122 mmHg and a Fatality Factor, F, of 2.2×10^{-6}.

5) Next the initiator frequency, P, which results in a Fatality Rate, Φ of $<10^{-7}$ is found. A fatality Rate of $<10^{-7}$ corresponds to an ODH 0 classification.

$$P = \Phi/F$$

6) Solving yields an allowable initiator frequency of P = 0.045 per hr to maintain an ODH 0 classification. This means that this major helium leak into the ERL helium recovery building, other pressure boundary failures with lower spill rates and human error resulting in a release of inert gas in the helium recovery building could occur every 22 hours and still allow the building to be classified as an ODH 0 area.

7) This initiator frequency is obviously unrealistically high compared to a credible frequency. Thus, controlling the ERL helium recovery building as an ODH 0 area is acceptable and appropriate.

This calculation was checked by Peter Cirnigliaro.

References

1. Email from Y. Than to R. Karol dated 1/8/08, ERL ODH Data
2. BNL Standards Based Management System Subject Area, ODH Classification/Controls
3. R.F. Barron, *Cryogenic Systems*, 2nd Edition, 1985, Oxford University Press, NY. Appendices B and D.

APPENDIX 3

C-AD Shielding Policy

From the C-AD SAD:

Collider-Accelerator Department Shielding Policy

The main features of the shielding policy for C-AD facilities are currently delineated in the Collider-Accelerator Department Operations Procedure Manual.[1, 2] The principal components of this policy are reviewed here for completeness. The primary purpose of the shielding policy is to assure that all radiation related requirements and administrative control levels are satisfied. Specifically, the Collider-Accelerator Department's Radiation Safety Committee reviews facility-shielding configurations to assure:

1. Annual site-boundary dose equivalent is less than 5 mrem.
2. Annual on-site dose equivalent to inadvertently exposed people in non-Collider-Accelerator Department facilities is less than 25 mrem.
3. Maximum dose equivalent to any area where access is not controlled is limited to less than 20 mrem during a fault condition.
4. For continuously occupied locations, the dose equivalent rate is ALARA but in no case greater than 0.5 mrem in one hour or 20 mrem in one week.
5. Dose equivalent rates where occupancy is not continuous is ALARA, but in no case exceeds 1 rem in one year for whole body radiation, or 3 rem in one year for the lens of the eye, or 10 rem in one year for any organ.

In addition to review and approval by the Radiation Safety Committee, final shield drawings must be approved by the Radiation Safety Committee Chair or the ESHQ Associate Chair. Shield drawings are verified by comparing the drawing to the actual configuration. Radiation surveys and fault studies are conducted to verify the adequacy of any new or modified shield configuration. The fault study methodology that is used to verify the adequacy of shielding is proscribed by additional Collider-Accelerator Department procedures, which are not elaborated here.[3] Any modifications to shielding configurations are likewise closely proscribed. Each facility and experiment is assigned a Liaison Physicist and Liaison Engineer. The Liaison Physicist is responsible, in consultation with the Radiation Safety Committee where appropriate, for determining safe conditions for any shielding modifications. The Liaison Engineer is responsible for ensuring that the safe conditions are met, for effecting any modification, and for notifying other responsible Collider-Accelerator Department personnel, including the Operations Coordinator, as well as experimenters both prior to and on completion of the modifications. Additional procedures exist to ensure that policy with respect to control of radioactive shielding is implemented, which are not elaborated here.

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[1] http://www.agsrhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-12.PDF Procedure for Review of Collider-Accelerator Department Shielding Design

[2] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch08/08-13.PDF Collider-Accelerator Department Procedure for Shielding/Barrier Removal, Removal of Primary Area Beam Line Components, or Modifications

[3] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-09.PDF Fault Study Procedure for Primary and Secondary Areas

APPENDIX 4

Accelerator Safety Envelope

Accelerator Safety Envelope

Title of Facility: Prototype Energy Recovery Linac (ERL)

Date of Initial ASE: June 30, 2008

Subsequent Revision Dates:

Version of the SAD that the ASE applies to: Prototype ERL SAD 6-30-08

Signature of Preparer:

____

Signature of Collider-Accelerator Associate Chair for Superconducting Accelerator R&D:

____

Signature of Collider-Accelerator Department Chair:

____

Signature of Nuclear and Particle Physics Associate Laboratory Director:

____

Signature of Deputy Director for Operations:

____

ASE Contents:

Section 1. Introduction

The ASE Requirements herein define the conditions, safe boundaries, and the administrative controls necessary to ensure safe Prototype ERL operations and to reduce the potential risk to the public, workers and environment.

1.1 The reference to the method used by the Collider-Accelerator Department for change control of the ASE is the BNL Subject Area on Accelerator Safety.

1.2 A variation beyond the boundaries described in Sections 2, 3, and 4 of this ASE shall be treated as a violation of the ASE and shall be a reportable occurrence, as defined by the BNL SBMS Subject Area on Occurrence Reporting. A violation is defined as not satisfying a Requirement or its specific Authorized Alternative. C-A Department staff shall make notifications of occurrences according to the requirements in the C-A Operations Procedure Manual.

1.2.1 If a Requirement is not satisfied and it has a specific Authorized Alternative, implement the Authorized Alternate or stop the activity that uses the affected equipment within one hour.

1.3 Emergency actions may be taken that depart from these approved ASE Requirements when no actions consistent with the Requirements are immediately apparent and when these actions are needed to protect the public, worker and environmental safety. These actions shall be approved by the person in charge of facility safety, as defined in the operating procedures, when the emergency occurs and shall be reported to C-AD management within 2-hours.

Section 2: BNL Safety Envelope Limits

This section contains the absolute limits that BNL places on Prototype ERL operations to ensure that BNL meets regulatory limits established to protect our environment, public and staff/visitors and that those operations are conducted within the assumptions of the Prototype ERL safety analyses documented in the **Prototype ERL SAD, 6-30-08**. BNL Safety Envelope Limits for Prototype ERL operations are:

2.1. Less than 25 mrem in one year to individuals in other BNL Departments or Divisions adjacent to this Collider-Accelerator Department accelerator facility.

2.2. Less than 5 mrem in one year to a person located at the site boundary.

2.3. Offsite drinking water concentration and on-site potable well water concentration must not result in 4 mrem or greater to an individual in one year.

2.4. Less than 1250 mrem in one year to a Collider-Accelerator Department staff member.

2.5. Less than 10,000 pCi/L in the BNL sanitary sewer effluent due to liquid discharges from Prototype ERL facilities.

2.6. In order to protect groundwater, if the annual activity concentration of sodium-22 or tritium in leachate is calculated to exceed 5% of the Drinking Water Standard, then a cap shall be used unless BNL Management is convinced otherwise.[1]

2.7. All emissions from Prototype ERL facilities are managed in accordance with the Air Emissions subject area.[2] If emissions are anticipated to exceed 0.1 mrem per year to the Maximally Exposed Individual, actions will be taken to ensure operations comply with NESHAP requirements including continuous emissions monitoring and permitting.

Section 3: Corresponding Prototype ERL Safety Envelope Parameters

This section identifies the measurable limitations on critical operating parameters that, in conjunction with the specifically identified hazard control considerations established by the facility design and construction, ensure that Prototype ERL operations will not exceed the corresponding Safety Envelope Limits discussed in Section 2. These parameters are derived from the safety analyses described in the **Prototype ERL SAD, 6-30-08**. Prototype ERL safety envelope parameters are:

Prototype ERL Beam Limits in Terms of Electron Energy and Beam Power

3.1 Electron energy limit of 3.5 MeV for the super-conducting RF gun.

3.2 The power source of the superconducting gun is limited to delivering 1.2 MW of power to the gun.

3.3 Electron energy limit of 25 MeV for the Prototype ERL ring.

3.4 Electron beam power shall not exceed the equivalent of 10 MW of instantaneous power for the electron beam in the Prototype ERL ring.

3.5 The power source for the five-cell cavity will be limited to delivering a maximum of 60 kW of power to the cavity.

3.6 A beam power of 1.2 MW for a 3.5 MeV electron beam striking the beam dump.

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[1] BNL SBMS Accelerator Safety Subject Area, Design Practice for Known Beam Loss Locations.
[2] BNL SBMS Subject Area, Radioactive Airborne Emissions.

Control of Beam Loss

3.7 Beam-loss-monitors, area-radiation monitors and area-radiation survey results shall be used in order to maintain beam loss "As Low as Reasonably Achievable" as defined in the BNL Radiological Manual.

Access Controls

3.8 The Access Controls System shall be functional during operations with beam.

3.9 During the running period, area radiation monitors that are interfaced with the Access Controls System shall be within their calibration date.

3.10 During the running period, the locations of area radiation monitors interfaced with the Access Control System are to be configuration controlled.

Fire Protection

3.11 During periods of beam operation, when access to the primary beam areas is prohibited the installed fire detection and protection systems shall be operable.

Authorized Alternative: Within 2 hours of discovery, the Department Chair or designee may allow partial or full inoperability of any fire detection or protection system for up to 80 hours with beam operations if the benefit of continuing Prototype ERL operations is judged to outweigh the potential risk of fire damage. Operating procedures shall specify the compensatory actions to be taken during inoperability.

3.12 Prototype ERL magnets and power supplies may be energized if the smoke detection system for the energized area can transmit an alarm to summon the BNL Fire/Rescue Group.

Authorized Alternative: The Operations Coordinator, ESH Coordinator or designee may allow partial or full inoperability of any fire detection system or manual alarm station in occupied areas as long as a Fire Watch is posted who can verbally communicate with the BNL Fire/Rescue Group by radio or phone.

Section 4: Engineered Safety Systems Requiring Calibration, Testing, Maintenance, and Inspection

The systems and requirements for calibration, testing, maintenance, accuracy or inspections necessary to ensure the integrity of the Prototype ERL safety envelope parameters during operations are given in this section:

4.1. The Access Control System shall be functionally tested in accordance with requirements in the BNL Radiation Control Manual.

4.2. Prototype ERL ventilation exhaust fans used to prevent an oxygen deficiency event shall undergo annual testing (not to exceed 15 months).

4.3. Prototype ERL fire protection shall undergo annual testing (not to exceed 15 months).

4.4. Area radiation monitors shall undergo annual testing (not to exceed 15 months).

4.5. Radiological barriers shall undergo annual visual inspection (not to exceed 15 months).

Section 5: Operations Envelop - Administrative Controls

Administrative controls necessary to ensure the integrity of the Prototype ERL safety envelope parameters during operations are:

5.1. Minimum Prototype ERL Control Room Staffing

5.1.1. Prototype ERL Control Room: one Trained Operator and one other person shall be on duty when Prototype ERL beam is in operation. During beam operations, one of the two must remain in the Prototype ERL Control Room at all times.

Authorized Alternative: If extra person is incapacitated, the remaining operator may continue operations as long as manning requirements are restored within two hours.

5.2. On-shift operations staff shall be trained and qualified on their safety, operational and emergency responsibilities. Records of training and qualification shall be maintained on the Brookhaven Training Management System (BTMS).

5.3. Work planning and control systems shall comply with the requirements in the C-A Operations Procedure Manual.

5.4. Environmental management shall comply with the requirements in the C-A Operations Procedure Manual.

5.5. Experiment modification and review shall comply with the requirements in the C-A Operations Procedure Manual.

5.5.1. Each upgrade in the Prototype ERL beam parameters or change of Prototype ERL configuration shall be reviewed before running with beam.

5.6. Annually, the C-AD Accelerator Systems Safety Review Committee shall review Prototype ERL's routine operations and facility for safety.

5.6.1. Prototype ERL may lie dormant for a period greater than one year between runs and does not require a review during the dormancy period.

5.7. Industrial hazards shall be controlled in accordance with the applicable portions of the BNL SBMS Subject Area.

5.8. Radiological area classifications during operations shall be in accord with requirements in the BNL Radiation Control Manual.

APPENDIX 5

Fault Study Results (Fault studies to be added following Commissioning)

Beam fault studies are conducted using the minimum beam intensity necessary to complete the study efficiently and consistent with ALARA practices. The beam is "ON" in the fault condition only as long as necessary for adequate survey measurements to be taken. Data for the fault study is kept on record and is used to verify that shielding is adequate for anticipated operations.

Fault studies will be performed after the Prototype ERL accelerator commissioners have control of the beam. Post-commissioning fault-study data will be recorded into this Appendix to the Prototype ERL SAD after the commissioning process is complete. Any changes to the shield design, as a result of a fault study finding, will be addressed in a USI to the SAD. Since fault studies are a post-SAD activity, dose rate calculations in Chapter 4 of the SAD are used to make initial estimates of radiation levels in order to implement appropriate radiological controls for commissioning. These controls, once proven effective by the fault study, verify the long-term radiological controls to be used during Prototype ERL operations.

APPENDIX 6

Qualitative Risk Assessments

Table A6-1 Qualitative Risk Assessment for Prototype ERL - Vacuum

FACILITY NAME: Prototype ERL
SYSTEM: Vacuum Beam Line
SUB-SYSTEM: Vacuum System, Beam Window
HAZARD: Vacuum

Event	Structural failure of vacuum boundary
Possible Consequences, Hazards	Implosion of any vacuum component could pose a potential health risk from flying objects or high noise.
Potential Initiators	Failure caused by worker mistake or inadvertent striking contact with vacuum boundary.

Risk Assessment Prior to Mitigation

Consequence	() High	() Medium	(X) Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low
Hazard Mitigation	1. Beam line vacuum components designed to meet consensus standards for compressive stress 2. Vacuum and pressure systems reviewed by the C-AD Chief Mechanical Engineer or his designate and BNL LESHC Pressure Safety Committee 3. Vacuum components, except for windows, are constructed of heavy-walled material, per ASME Boiler and Pressure Vessel Code, Section VIII or equivalent to minimize the threat of implosion when evacuated 4. Many windows are covered 5. Training of Users and Staff			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A6-2 Qualitative Risk Assessment for Prototype ERL – External Events

FACILITY NAME: Prototype ERL
SYSTEM: Entire Facility
SUB-SYSTEM: N/A
HAZARD: External Event (Earthquake, Tornado, Hurricane, Flood, Aircraft Impact, Forest Fire, near ERL facility)

Event	External event impacts ERL
Possible Consequences, Hazards	Personnel injuries, equipment/building damage or programmatic impact
Potential Initiators	Earthquake, severe weather, flooding, fire, aircraft impact

Risk Assessment Prior to Mitigation

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	() Anticipated High	() Anticipated Medium	() Unlikely	(X) Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low
Hazard Mitigation	1. Building designed to Uniform Building Code and designed to meet DOE O 420.1B, Facility Safety 2. Small radioactive inventory cannot cause offsite impacts 3. BNL Fire Group can respond quickly to forest fire; BNL has firebreaks 4. BNL Fire Group can respond quickly to fire near ERL 5. No active systems needed to protect personnel from adverse health effects after ERL off 6. Severe weather and flooding potential is extremely low; warning of these impending hazards will allow for ERL shutdown and for personnel safety 7. BNL Wildfire Prevention Program			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A6-3 Qualitative Risk Assessment for Prototype ERL – Electric Shock/Arc Flash

FACILITY NAME: Prototype ERL
SYSTEM: Facility
SUB-SYSTEM: Magnets, Power Supplies, Instrumentation
HAZARD: Electric Shock/Arc Flash from Exposed Conductors and Operating Breakers/Disconnects

Event	Worker contacts energized conductor and receives electrical shock or experiences arc flash while operating breakers/disconnects
Possible Consequences, Hazards	Shock, impact injury, arc flash burns
Potential Initiators	Worker falls, fails to control position of limbs or tools, equipment failure, improper work controls, improper PPE use

Risk Assessment Prior to Mitigation

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	(X) High Risk	() Medium	() Low Risk	() Extremely Low
Hazard Mitigation	1. Exposed conductors and terminals are covered or barriered for protection of personnel 2. Training for workers 3. Use of work planning, LOTO and Permits 4. Use of proper PPE and compliance with NFPA 70E 5. Magnets de-energized when routine work is done 6. Electrical equipment is NRTL, or review is performed for electrical safety on all non-NRTL and 'in-house' built equipment by a qualified Electrical Equipment Inspector			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A6-4 Qualitative Risk Assessment for Prototype ERL – Radiation External to Enclosure

Facility Name: Prototype ERL
System: Areas External to Shielded Components
Sub-System: Prototype ERL shielding and shield penetrations
Hazard: Prompt Beam Radiation

Event	Credible beam control fault
Possible Consequences, Hazards	Unwarranted radiation exposure due to abnormal radiation levels outside beam line components, penetrations and chicanes
Potential Initiators	Failure of magnet or magnet power supply, ineffective or inefficient beam tuning

Risk Assessment Prior to Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low
Hazard Mitigation	1. Primary beam will not penetrate shield materials 2. Beam tuned at low intensity and beam intensity limits 3. Operator and physicist training 4. Review of design of shields and penetrations by C-AD RSC; review of fault studies 5. Radiological area postings 6. Klystron Room locked 7. Routine area radiation surveys 8. Periodic inspection of shielding to verify integrity 9. Interlocking radiation monitors			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A6-5 Qualitative Risk Assessment for Prototype ERL – Radiation Inside Enclosure

FACILITY NAME: Prototype ERL
SYSTEM: Shielded Enclosures
SUB-SYSTEM: Prototype ERL Enclosure, Klystron Room
HAZARD: Prompt Beam Radiation inside Shielded Enclosures

Event	Person inside enclosure during operation
Possible Consequences, Hazards	Personal injury or death due to external prompt radiation associated with beam
Potential Initiators	Person inadvertently enters enclosure; person fails to leave before beam initiated

Risk Assessment Prior to Mitigation

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low
Hazard Mitigation	1. Operating procedures 2. Worker / User training 3. Review of facility design by C-AD RSC 4. ERL Enclosure and Klystron Room sweep procedures 5. ACS door locks and other access controls 6. Audible/visual alarms initiated by ACS inside enclosures before beam initiation, allowing sufficient time for un-swept individuals to manually stop beam initiation or exit enclosure to stop beam initiation 7. ACS automatic interlock to stop beam if access violation 8. ACS controls critical devices to automatically confine beam to enclosure, thus keeping beam out of downstream section with personnel inside			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement.

Table A6-6 Qualitative Risk Assessment for Prototype ERL – Activation of Components

FACILITY NAME: Prototype ERL
SYSTEM: Beam Dump, Other Activated Components
SUB-SYSTEM: N/A
HAZARD: External Radiation from Activated Beam Dump, Activated Magnets and Other Components

Event	Worker / Physicist inside ERL Cave during beam off periods
Possible Consequences, Hazards	Excessive external dose
Potential Initiators	Improper work planning, procedure violation

Risk Assessment Prior to Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low
Hazard Mitigation	1. Beam tuning keeps activation of magnets and beam–line components to a minimum 2. Work planning prior to authorizing start of work 3. Radiological surveys of work areas 4. RWP issued prior to start of work 5. ALARA design and administrative controls 6. C-AD ALARA Committee reviews jobs and designs 7. Worker and operator training 8. Radiological postings warn personnel of high dose rates 9. Personnel entering High Radiation Areas wear alarming self-reading dosimeters			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A6-7 Qualitative Risk Assessment for Prototype ERL – Conventional/Industrial Hazards

FACILITY NAME: Prototype ERL
SYSTEM: Entire Facility
SUB-SYSTEM: All Sub-systems
HAZARD: Noise, Pressure, Hazardous Atmospheres, Magnetic and RF Fields, Hoisting and Rigging Hazards, Heights, Cryogenic Fluids, Chemicals, Flammable / Explosive Gases, Falling Objects, Hot Surfaces, Trip Hazards, Welding/Cutting

Event	Injury resulting from industrial hazard
Possible Consequences, Hazards	Worker/physicist injury or death
Potential Initiators	Improper work planning, procedure violation

Risk Assessment Prior to Mitigation

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	(X) High Risk	() Medium	() Low Risk	() Extremely Low
Hazard Mitigation	1. Work planning prior to authorizing start of work 2. Worker operator training 3. Review and audit of conventional safety issues by C-AD staff and ESH experts during Tier 1, work planning and/or ESH appraisals 4. Design review of accelerator modifications by ASSRC and qualified engineers 5. Meeting safety requirements defined by BNL SBMS 6. Meeting requirements in 10CFR851 7. Environmental reviews 8. Manager work observations			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A6-8 Qualitative Risk Assessment for Prototype ERL – Airborne Releases

FACILITY NAME: Prototype ERL
SYSTEM: Ventilation System and Vacuum Pump Emissions
SUB-SYSTEM: Exhaust Systems
HAZARD: Radioactive or Hazardous Materials

Event	Uncontrolled release of airborne radioactive or hazardous materials
Possible Consequences, Hazards	Adverse health effects to workers (public health effects not possible)
Potential Initiators	Improper work planning, violation of procedures, human error

Risk Assessment Prior to Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low
Hazard Mitigation	1. Radioactive airborne concentrations are insignificant 2. Work planning prior to authorizing start of work 3. Worker and operator training 4. Conduct of Operations system 5. Review of accelerator modifications by C-AD ASSRC 6. Review and monitoring of IH airborne hazards by C-AD ESSHQ Division 7. Meeting requirements defined by BNL SBMS 8. Environmental Management System 9. OSH Management System 10. Chemical Management System			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A6-9 Qualitative Risk Assessment for Prototype ERL – Environmental

FACILITY NAME: Prototype ERL
SYSTEM: Cooling Water System
SUB-SYSTEM: Radioactive Water
HAZARD: Soil and Groundwater Contamination

Event	Spill of activated cooling water to soil
Possible Consequences, Hazards	Groundwater contamination, internal dose to BNL personnel or public
Potential Initiators	Water pressure boundary failure, procedure violation, improper work planning

Risk Assessment Prior to Mitigation

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

Hazard Mitigation	1. Radioactive liquid concentrations are insignificant 2. Work planning prior to authorizing start of work 3. Worker and operator training 4. Conduct of Operations system 5. Review of accelerator modifications by C-AD ASSRC 6. Meeting requirements defined by BNL SBMS 7. Environmental Management System 8. Chemical Management System 9. Extensive groundwater monitoring well system and groundwater-sampling program 10. Suffolk County Article 12 Code is followed in the design of cooling water systems and piping that contain significant amounts of tritium

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A6-10 Qualitative Risk Assessment for Prototype ERL – Loss of Electrical Power

FACILITY NAME: Prototype ERL
SYSTEM: Entire Facility
SUB-SYSTEM: N/A
HAZARD: Hazards Produced As Power Is Lost To Equipment

Event	Loss of offsite power, local loss of power
Possible Consequences, Hazards	Personal safety hazards, programmatic loss
Potential Initiators	Equipment failure or operator error

Risk Assessment Prior to Mitigation

Consequence	() High	() Medium	() Low	(X) Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	() Medium	(X) Low Risk	() Extremely Low
Hazard Mitigation	1. Integrated Safety Management program assures proper work planning prior to authorizing start of work 2. Worker and operator training 3. Review of conventional safety by C-AD ASSRC and BNL ESH Committees 4. Backup power supplied to required systems to reduce programmatic impact 5. ERL automatically shuts down upon loss of electrical power 6. Emergency lighting 7. BNL and ERL emergency procedures			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table A6-11 Qualitative Risk Assessment for Prototype ERL – Fire

FACILITY NAME: Prototype ERL
SYSTEM: Entire Facility
SUB-SYSTEM: N/A
HAZARD: Personal Injury or Equipment Damage

Event	Magnets, power and control cables, laboratory equipment combustion
Possible Consequences, Hazards	Injury/death, programmatic impact
Potential Initiators	Loss of cooling to magnets or power supplies, transient combustibles start fire which spreads, electrical component overheating, flammable/combustible gas ignition, human error

Risk Assessment Prior to Mitigation

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low
Hazard Mitigation	1. Combustible loading is minimized 2. Periodic safety inspections 3. Safety training 4. Fire detection and suppression system 5. Design reviewed by BNL Fire Protection Engineer 6. Design meets NFPA requirements 7. Ventilation system 8. Conventional safety reviewed by C-AD ESRC 9. B912 FHA and implementation of protections			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement.

Table A6-12 Qualitative Risk Assessment for Prototype ERL – Oxygen Deficiency Hazards

FACILITY NAME: Prototype ERL
SYSTEM: ERL Facilities
SUB-SYSTEM: Cryogenic liquids, inert gas use/storage
HAZARD: Oxygen Deficiency

Event	Breathing air displaced causing reduced oxygen concentration
Possible Consequences, Hazards	Illness, asphyxiation
Potential Initiators	Significant release of gases to area or room

Risk Assessment Prior to Mitigation

Consequence	(X) High	() Medium	() Low	() Extremely Low
Frequency	() Anticipated High	(X) Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low
Hazard Mitigation	1. ODH hazards analyzed and controls in place as per BNL SBMS requirements 2. Work planning and LOTO 3. Review of ODH hazards and controls by C-AD ASSRC 4. Review of ODH hazards and controls by BNL PCSS 5. Cryogenic pressure boundary designs meet ASME Code and appropriate consensus stands designs and testing requirements			

Risk Assessment Following Mitigation

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

Is the mitigated hazard adequately controlled by existing BNL policies? Y/N Yes If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N Yes If Yes, need ASE requirement.

APPENDIX 7

Cooling Water Activation

Water Activation in ERL Test Area

D. Beavis
May 5, 2006
Amended May 8, 2006

A simple estimate is made below for the expected radioactive concentrations in water at the ERL test area for the dipole magnets.

W.P. Swanson (Ref. 1) provides a simple method to estimate the radioactive saturation concentrations in water for electron beams stopped in water. Table XXXIIa lists the activation products per kW of stopped electrons in water (numbers provided below). It is suggested that for electron energies at or below 50 MeV that the numbers for O-15 be reduced by a factor of two and the other isotopes can have a larger reduction factor. A reduction of a factor of two will be used.

The Bremsstrahlung photons only have a small fraction of their path length in the cooling water of the dipole magnets. It the water is approximated as a sheet of water from the magnet mid-plane to the top of the coil, it has dimensions 6.85cm by 0.23 cm thick. To account for the small photon path length in water the activation will be reduced by the thickness divided by 2 radiation lengths (0.23cm/72cm). Coupled with the factor of two discussed above the total reduction in activity will be 0.0016. The routine loss of 50 MeV electron beam is expected to be 0.1 kW. It will be assumed that the beam loss occurs near a dipole. The activities with the expected beam loss and the total reduction factor are shown in the third column of the table below.

The expected saturation activities are:

Nuclide	Sat. Activity (GBq/(kW))	Reduced GBq
O-15	330	0.053
O-14	3.7	0.0006
N-13	3.7	0.0006
C-11	15.	0.0024
C-10	3.7	0.0006
Be-7	1.5	0.00024
H-3	7.4	0.0012

Several factors are needed to get the concentration and expected dose rates. From the numbers above the activity and dose will be dominated by the O-15 so we will ignore the other concentrations. The water system has a volume of approximately 2300 liters (600 gallons). The saturation concentration of O-15 is 23 Bq/cc. Estimates of the potential dose rate will require information on the water geometry and the conversion factor for gamma rate to dose. Following the discussion of Sullivan (Ref 2.) we will assume that the decays of O-15 will produce two 0.51 MeV gammas. We have a conversion factor (see Ref. 2) of 2.31*10**-10 rads/(gamma-cm**2).

The dose rate will be estimated at the surface for a 30cm diameter sphere of water and a 164 cm diameter sphere (entire water volume). The surface dose rates are (ignoring any self shielding):

164 cm diameter sphere 0.5 mrad/hr
30 cm diameter sphere 0.1 mrad/hr

Based on the approximations discussed above it is expected that the actual concentrations and dose rates will be smaller.

The tritium concentration can be obtained from the numbers above. The saturation activity is equal to the production rate. The production rate is therefore 1.2*10**6 H-3 atoms/s. The beam is expected to be operated for 40 hours per month and nine months per year for a total of 1.3*10**6 seconds per years. The water system has a volume of 2300 liters. The expected concentration of tritium in the cooling water after one year of operation is 6.8*10**8 H-3 atoms/liter. The activity is the decay constant times the number of atoms. The decay constant for tritium is 1.8*10**-9/sec and 1 Ci = 3.7*10**10 decays per second. The activity concentration for tritium is 33 pCi/liter after one year of operation.

References

1. W.P. Swanson, Radiological Safety Aspects of the Operation of Electron Linear Accelerators, Tech. Rep. Series No. 188, Int. At. Energy Agency, Vienna, 1979.
2. A.H. Sullivan, A guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, 1992

APPENDIX 8

Air Activation

Air Activation in ERL Test Area

D. Beavis
May 3, 2006

A simple estimate is made below for the upper limit on the expected radioactive air concentrations in the ERL test area.

W.P. Swanson (Ref. 1) provides for a simple method to estimate the radioactive saturation concentrations in air that are produced by electron beams. It is assumed that the electron beam is incident on a high-Z thick target. Numbers for the saturation activity are given in Table XXXa of Reference 1. It is expected that the actually targeting conditions will create less activity. In addition, the close in shielding which is expected to attenuate the forward Bremsstrahlung for ERL will further reduce the air radioactive concentrations. To utilize Table XXXa of Reference 1 a few numbers are needed for the ERL test area.

I have approximated the room dimensions as 8.5m by 20.7m by 2.74 m. I will further assume that the average distance in air from a loss point to a wall is on the average 4 meters. Finally I will assume that the routine 50MeV loss is 100 Watts.

The expected saturation concentrations are:

Nuclide	Average room saturation activity Concentration (Bq/cc)
H-3	$4.2*10^{-3}$
Be-7	$8.3*10^{-4}$
C-11	$2. *10^{-5}$
N-13	$4. *10^{-1}$
O-15	$4.6*10^{-2}$
N-16	$1.7*10^{-5}$
Cl-38	$1.8*10^{-4}$
Cl-39	$1.3*10^{-3}$

References

1. W.P. Swanson, Radiological Safety Aspects of the Operation of Electron Linear Accelerators, Tech. Rep. Series No. 188, Int. At. Energy Agency, Vienna, 1979.