EBIS Pre-Injector, Building 930

Unreviewed Safety Issue (USI) Document

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D R A F T

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1. Introduction

The EBIS Pre-Injector USI is a temporary document used to supplement the Collider-Accelerator Department's Safety Assessment Document (C-AD SAD). Previously written and approved sections of the C-AD SAD that are applicable to the EBIS Pre-Injector are referenced in this USI; only information that relates to EBIS's specific hazards, controls or risks is found in this USI. This EBIS-specific information will be incorporated into the next updated version of the C-AD SAD.[1]

1.1. Scope

This document presents a basic understanding of the mission associated with the Electron Beam Ion Source (EBIS) Pre-Injector in Building 930, the protections that are afforded the public and the workers' health and safety, and the protection of the environment from radiological and other hazards associated with the ion source.

1.2. Basic Understanding of Pre-Injector Activities

The mission associated with the Pre-Injector in Building 930 is to generate and accelerate beams of ions, from deuteron ion beams to uranium ion beams, for the Relativistic Heavy Ion Collider (RHIC) and the NASA Space Radiation Laboratory (NSRL). The Pre-Injector is based on a high-charge-state EBIS, a Radio Frequency Quadrupole (RFQ) accelerator, and a short Linear accelerator (Linac). Figure 1.2.a shows the planned layout of the Pre-Injector, and Figures 1.2.b and 1.2.c show the planned location of the Pre-Injector components in Building 930. Figure 1.2.d shows the layout of the high voltage components in a protective cage.

[1] C-AD Safety Assessment Document

Figure 1.2.a Drawing of Electron Beam Ion Source Layout

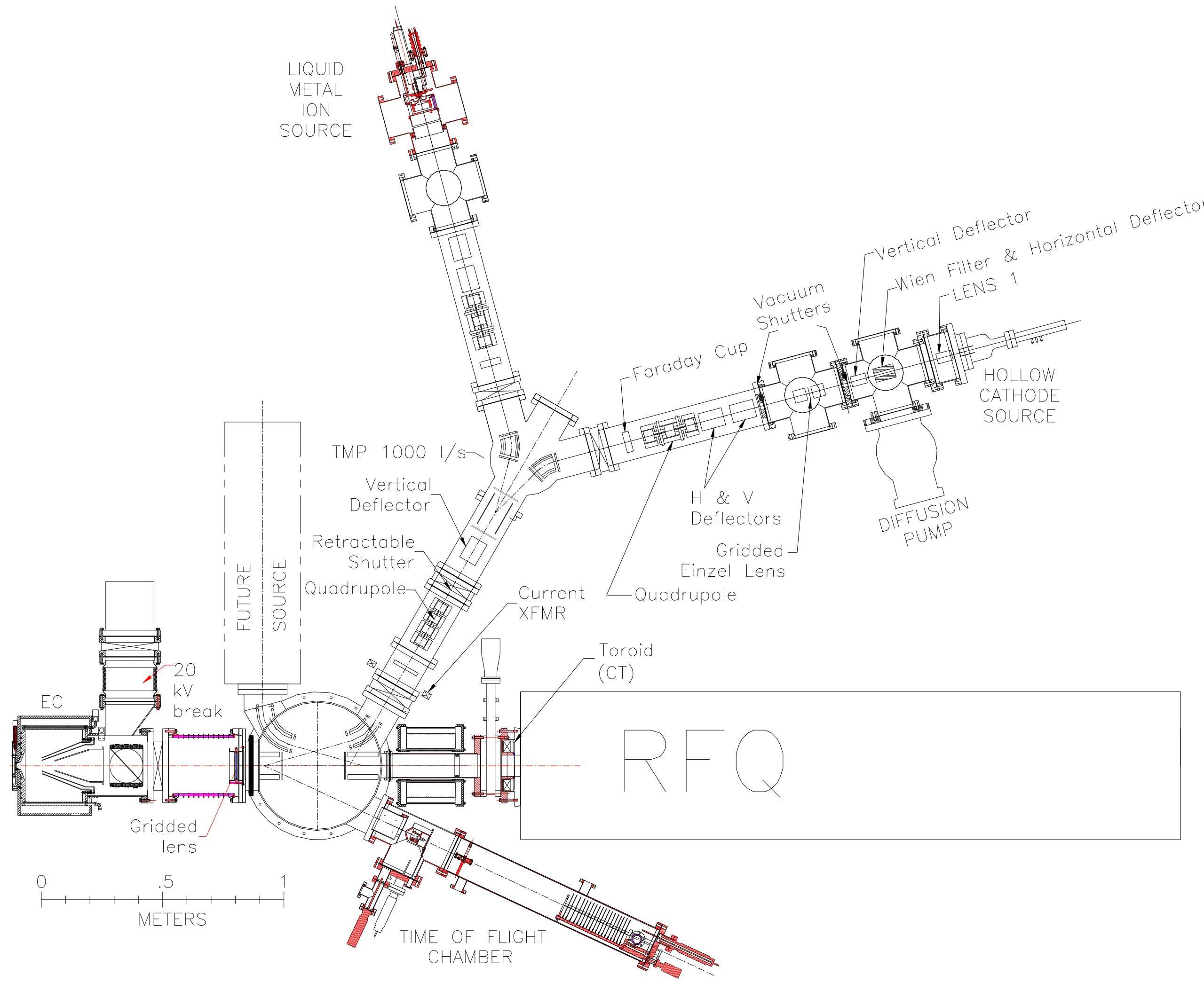


Figure 1.2.b EBIS Floor Plan in Building 930 Lower Level

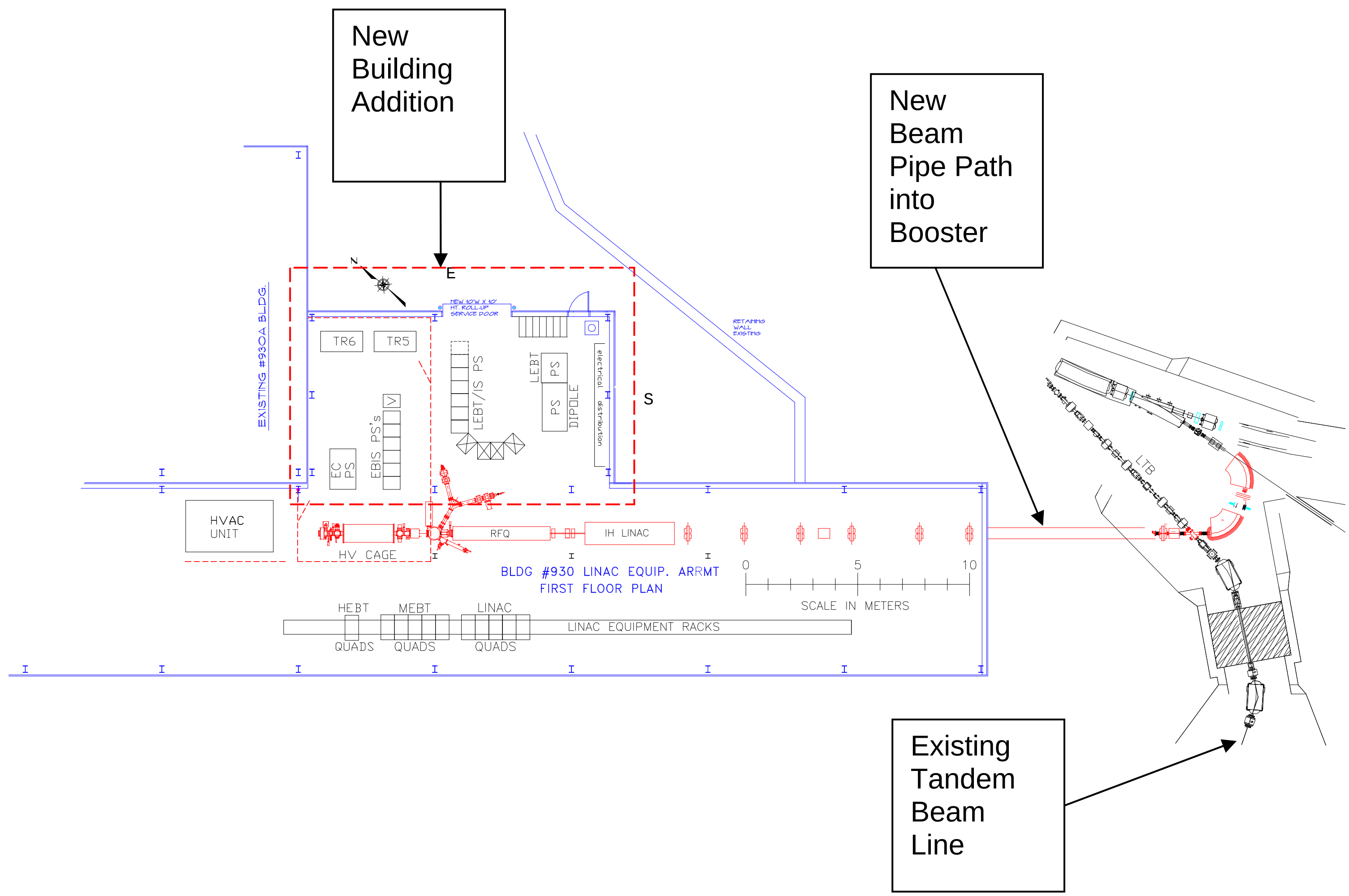


Figure 1.2.c EBIS Floor Plan in Building 930 Upper Level

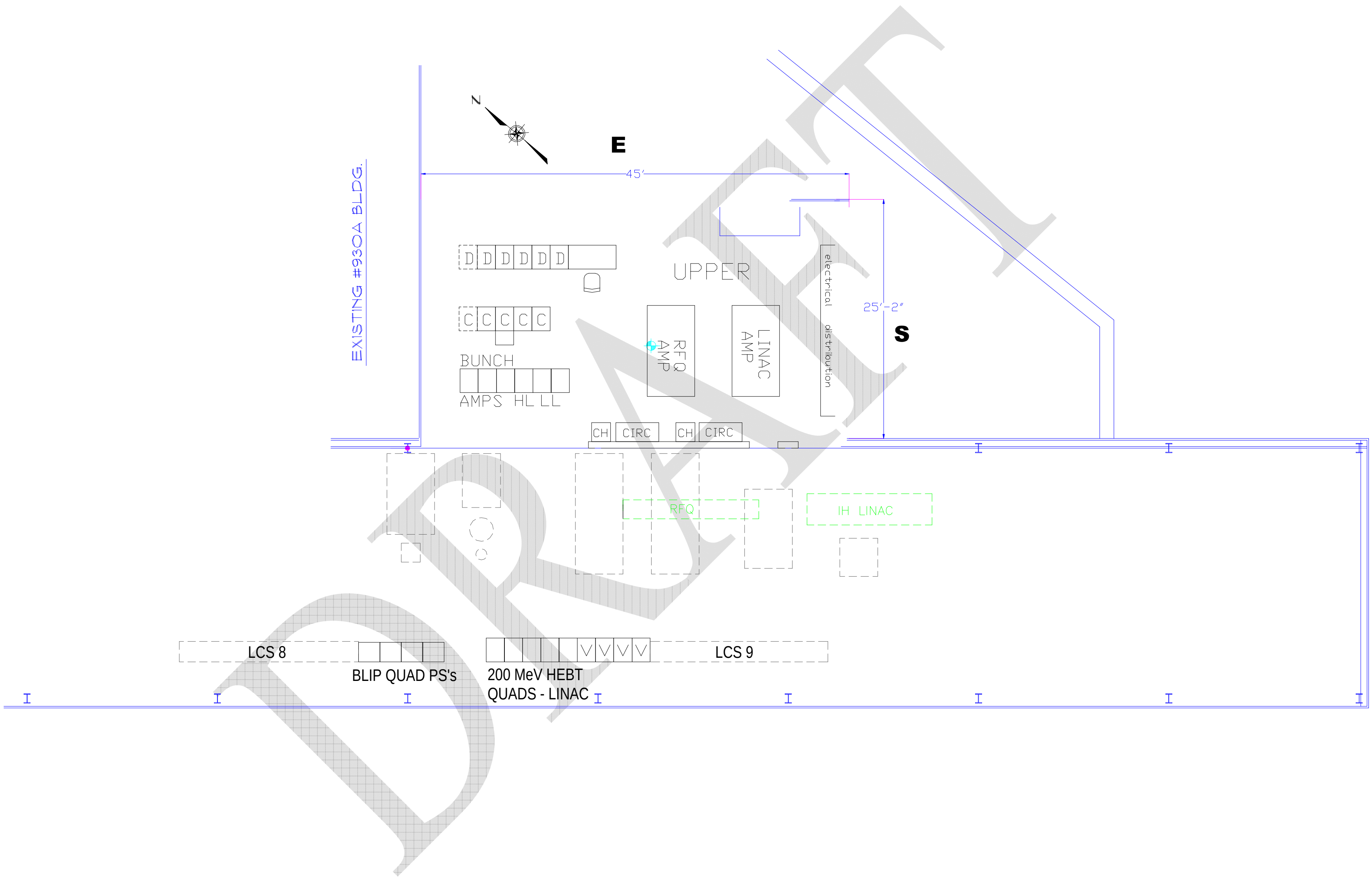
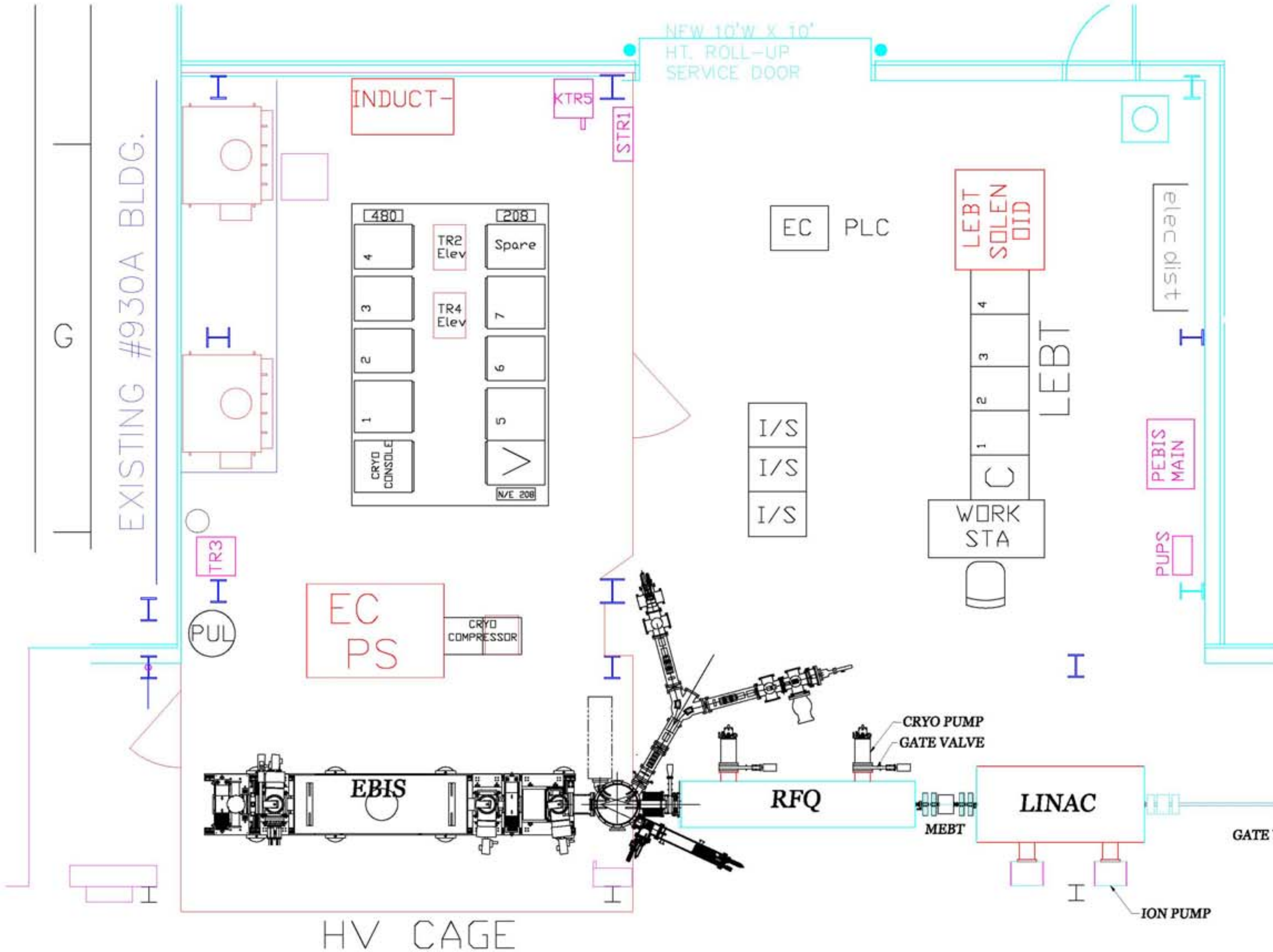


Figure 1.2.d High Voltage Safety Cage for EBIS Power



The EBIS at Brookhaven National Laboratory (BNL) replaces the present Tandem Van de Graaff Pre-Injector that was built in 1970 with a reliable low-maintenance small Linac-based pre-injector. Linac-based pre-injectors are used at most accelerator and collider facilities with the exception of RHIC, where the required gold beam intensities could only be met with a Tandem until the recent EBIS was developed.

EBIS produces high charge state ions directly, eliminating the need for the two stripping foils presently used with the Tandem. Unstable stripping efficiencies of these foils are a significant source of luminosity degradation in RHIC.

The high reliability and flexibility of the new Linac-based pre-injector will lead to increased integrated luminosity at RHIC and is an essential component for the long-term success of the RHIC facility. This new pre-injector has the potential for significant future intensity increases and can produce heavy ion beams of all species including uranium beams. These capabilities are critical to the future luminosity upgrades and electron-ion collisions in RHIC.

The new Linac-based pre-injector system provides for a major enhancement in capability for the NASA Space Radiation Laboratory (NSRL), which utilizes heavy-ion beams from the RHIC complex. EBIS allows for the acceleration of all important ion species for the NASA radiobiology program, such as, helium, argon, and neon which are unavailable with the present Tandem injector. In addition, the new system allows for very rapid switching of ion species for NSRL experiments, reducing delays due to the interference with RHIC injection operations, and allowing enhanced mixed field radiation studies.

The new RFQ and Linac that are used to accelerate beams from the EBIS to energy sufficient for injection into the Booster are both very similar to existing devices already in operation at other facilities. Injection into the Booster occurs at the same location as the existing injection from the Tandem.

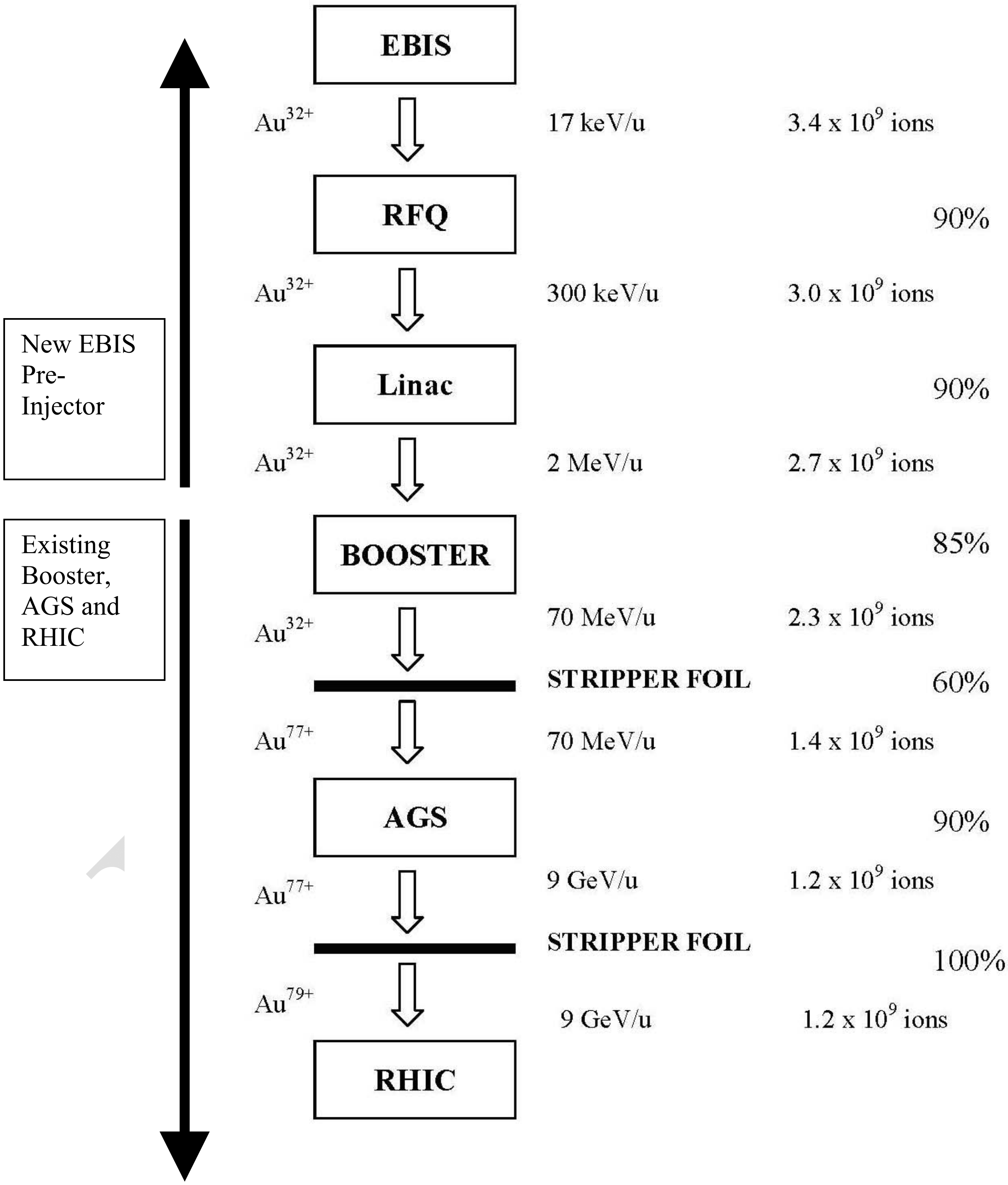
An EBIS delivers ion pulses having a constant total positive charge, and one has control over the pulse width by controlling the release of the trap voltage. Ions are extracted in short pulses of high current, which is desirable for synchrotron injection. EBIS parameters are given in Table 1.2.

Table 1.2.a EBIS Parameters

e-beam current	10 A
e-beam energy	20 keV
e-beam density	~575 A/cm^2
Ion trap length	1.5 m
Trap capacity (charges)	11 x 10^{11}
Yield positive charges	5.5 x 10^{11}
Pulse length	$\leq$ 40 μs
Yield Au^{32+} design value	3.4 x 10^9 ions/pulse

A schematic of the injection scheme with the new injector is shown in Figure 1.2.d, with intensities given for Au^{32+}. The EBIS operates with a 10 A electron beam and produces in excess of 5x10^{11} charges/pulse for any desired species. For heavy ions, ~20% of these ions are in the desired single charge state, while for light ions this fraction can reach ~ 50%. In addition, key components (electron gun and collector) were designed with the capability of operating at up to 20 A electron beam current, so one will have the potential of a factor of ~1.6 improvement in electron trap capacity and ion charge yield.

Figure 1.2.d Injection Scheme for EBIS Operations



It is noted that the DOE approved maximum number of heavy ions in each RHIC ring may not exceed the equivalent of 2.4×10^{11} Au ions at 100 GeV/u and 2.4×10^{11} protons at 250 GeV per ring.[2]

The total kinetic energy per ring, 4.8×10^{15} GeV for Au and 6.0×10^{15} for protons, is essentially the same, and it is this quantity that determines radiological consequences. In order to derive secondary limits for other ion species for radiation protection purposes, Stevens constructed a version of Table 1.2.b below.[3] Table 1.2.b lists the equivalent beam energy per ring as a function of representative ion species. Since Stevens did not include He-3 and U-238 in his original table, these values were developed by Ahrens and explained in the paragraphs following the table.

Table 1.2.b Ion Species in RHIC

Species	Ions per Ring	Kinetic Energy (GeV/u)	Total Kinetic Energy per Ring (GeV)
Proton (A=1)	2.40×10^{13}	250	6.0×10^{15}
Deuterium (A=2)	2.40×10^{13}	125	6.0×10^{15}*
Helium (A=3)	1.00×10^{13}	167	5.0×10^{15}
Oxygen (A=16)	2.00×10^{12}	125	4.0×10^{15}
Silicon (A=28)	1.34×10^{12}	125	4.7×10^{15}
Copper (A=63)	6.48×10^{11}	115	4.7×10^{15}
Iodine (A=127)	3.60×10^{11}	104	4.8×10^{15}
Gold (A=198)	2.40×10^{11}	100	4.8×10^{15}
Uranium (A=238)	2.10×10^{11}	96.8	4.8×10^{15}

* Formerly set to half this value by Stevens due to higher than approved levels of prompt radiation from deuterons in the Tandem to Booster Line, which no longer applies when using the EBIS source.

[2] RHIC Accelerator Safety Envelope

[3] A. J. Stevens to H. Kahnhauser, BNL Memorandum, RHIC ASE as a Function of Ion Species, September 26, 2001.

The limit for the quantity of any ion species in RHIC is set by the total kinetic energy carried by a beam made up of that ion species at the highest RHIC magnetic field. Simply extending the same rule to U-238 (92+) and to He-3 (2+), ignoring the difference between kinetic energy and total energy (a 1% effect) and ignoring energy/u (u = atomic mass unit) versus energy/nucleon (a <<1% effect), then the same magnetic field to which RHIC magnets can ramp to contain gold at 100 GeV/n and protons at 250 GeV/n, will contain the He-3 ion in orbit until the He-3 ion reaches 167 GeV/n and until the U-238 ion reaches 96.8 GeV/n.

For He-3, the number of nucleons allowed is (4.8×10^{15} GeV) / (167 GeV/n) = 2.9×10^{13} nucleons or 0.96×10^{13} ions, which is rounded to 1.0×10^{13}. For uranium, the number of nucleons allowed is (4.8×10^{15} GeV) / (96.8 GeV/n) = 4.96×10^{13} nucleons or 2.1×10^{11} ions.[4]

It is noted that based on Sullivan, the radiation dose outside thick shielding grows less than linearly with kinetic energy, namely approximately as the kinetic energy of the beam raised to the 0.8 power.[5] The gold dose outside the RHIC shielding is proportional to (197) (2.4×10^{11}) $(100\ \text{GeV/u})^{0.8}$ and proton (1) (2.4×10^{13}) $(250\text{GeV/u})^{0.8}$. Numerically these two parameters that help determine dose differ by 5% instead of 20% if kinetic energy is taken as the parameter to compare. The answers for ions per ring do not change for He-3 and U-238 but the wide 20% difference in total kinetic energy per ring for Au vs protons now shrinks down to a more reasonable 5% difference in the predicted dose outside of the shielding.

[4] L. Ahrens, Intensity Limits in RHIC for Uranium-238 and Helium-3, October 4, 2007.
[5] A. H. Sullivan, A Guide to Radiation and Radioactivity levels near High Energy Particle Accelerators, Equation 2.4.

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

Engineered controls include fixed-location intEBIS Pre-Injectorocking area-radiation monitors and shielding where appropriate. Administrative controls include posting, fencing, training and qualifications for workers and visitors who may work at or enter the Linac near the EBIS Pre-Injector. Additional administrative controls may include personnel dosimeters, Radiation Work Permits and As Low As Reasonably Achievable (ALARA) reviews of maintenance and repair jobs when needed at the Booster end of the EBIS Pre-Injector. Radiation surveys using portable radiation monitors will be used to verify the radiological controls on a regular basis. The limit on the beam in the Pre-Injector is such that exposure to individuals in controlled and uncontrolled areas is designed to be less than the annual limits.

The Collider-Accelerator Department has embraced DOE's Integrated Safety Management System as a basic protection for workers and experimenters. In order to guide operations and maintenance of the accelerators, beam lines and associated systems at the Department level, an Administrative Control named "Work Planning and Control" is used. The same work planning requirements are used to guide staff operations and maintenance for the EBIS Pre-Injector.

1.4. Design Codes, Consensus Safety Standards, Regulations and DOE Orders Used To Establish Safety for Workers and the Public

The following requirements documents are used to establish safety requirements for the EBIS Pre-Injector and Building:

- 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
  - B31.5 2001 Refrigeration Piping and Heat Transfer Components, and B31.5a—2004, Addenda to ASME B31.5 2001
  - B31.9 1996 Building Services Piping
  - B31G 1991Manual for Determining Remaining Strength of Corroded Pipelines
  - Building Code of the State of New York
  - NFPA 101, Life Safety Code
- Consensus Safety Standards
  - 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)
  - BNL SBMS Subject Areas

- 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 STD-1020-2002, Natural Phenomena Hazards Design And Evaluation Criteria For Department Of Energy Facilities
  - DOE O 5480.19, Conduct of Operations
  - DOE Manual 231.1 1A, Environment, Safety and Health Reporting Manual, September 9, 2004

2. Summary/Conclusions

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

The EBIS Pre-Injector is classified as low-hazard, and is subject to the requirements of the DOE Accelerator Safety Order, DOE O 420.2B or its successors. These requirements are promulgated in BNL's SBMS Accelerator Safety Subject Area. A low-hazard facility is defined to be one with potential for no more than minor on-site and negligible off-site impacts to people and the environment. The possibility of any off-site impacts or major on-site impacts is highly unlikely due to the physical aspects of the EBIS Pre-Injector whereby it is dependent upon an external energy source; that is, electric power that can be easily terminated. The radiation hazard is confined to the beam pipe, and is in existence only when a beam is present.

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

Need to write up.

3. Site, Facility and Operations Description

3.1. Environment within Which the EBIS Is Constructed

The accelerator site location is characterized in the following paragraphs. Information addresses adjacent facilities that may impact EBIS Pre-Injector safety or operations. The treatment of site geography, seismology, meteorology, hydrogeology, and demography is found in the C-AD SAD.[6] Thus, it was not repeated here.

The EBIS Pre-Injector is located inside the 200-MeV Linac, which was designed and built in the late 1960's as a major upgrade to the AGS complex. The 200-MeV Linac's purpose is to provide accelerated high-intensity protons for use at AGS, polarized protons at RHIC, and high-intensity protons at a Medical Department facility known as the Brookhaven Linac Isotope Producer (BLIP). The EBIS Pre-Injector is located outside the Linac shielding near the high-energy end of the Linac (see Figure 3.2.a).

A building addition was made to Building 930, which houses the 200-MeV Linac, in order to accommodate power supplies and other equipment that supports the operation of the EBIS Pre-Injector. A plan view and a side view of the EBIS addition to Building 930 is shown in Figure 3.2.b.

[6] C-AD Safety Assessment Document

Figure 3.2.a Loacation of EBIS Pre-Injector

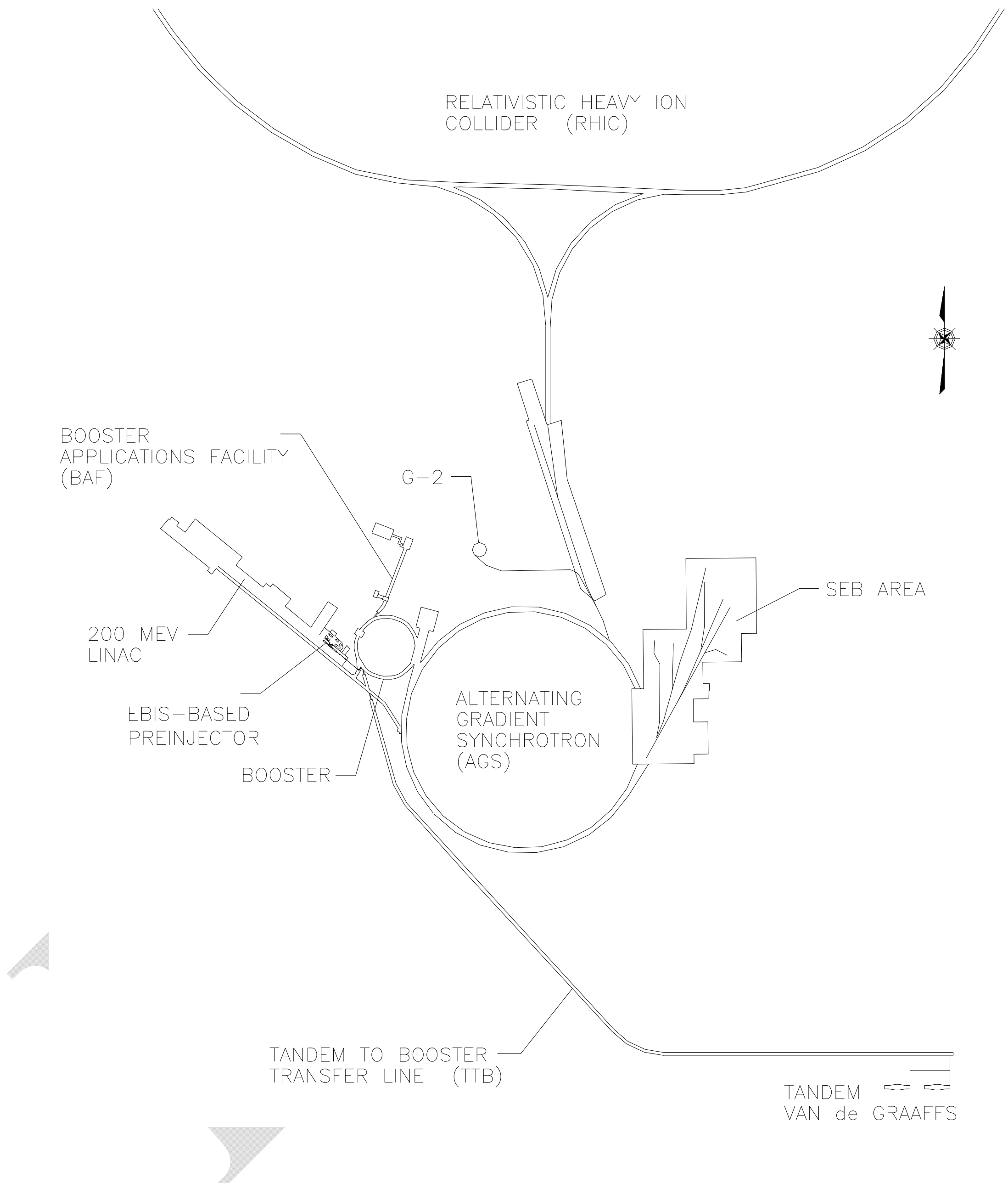
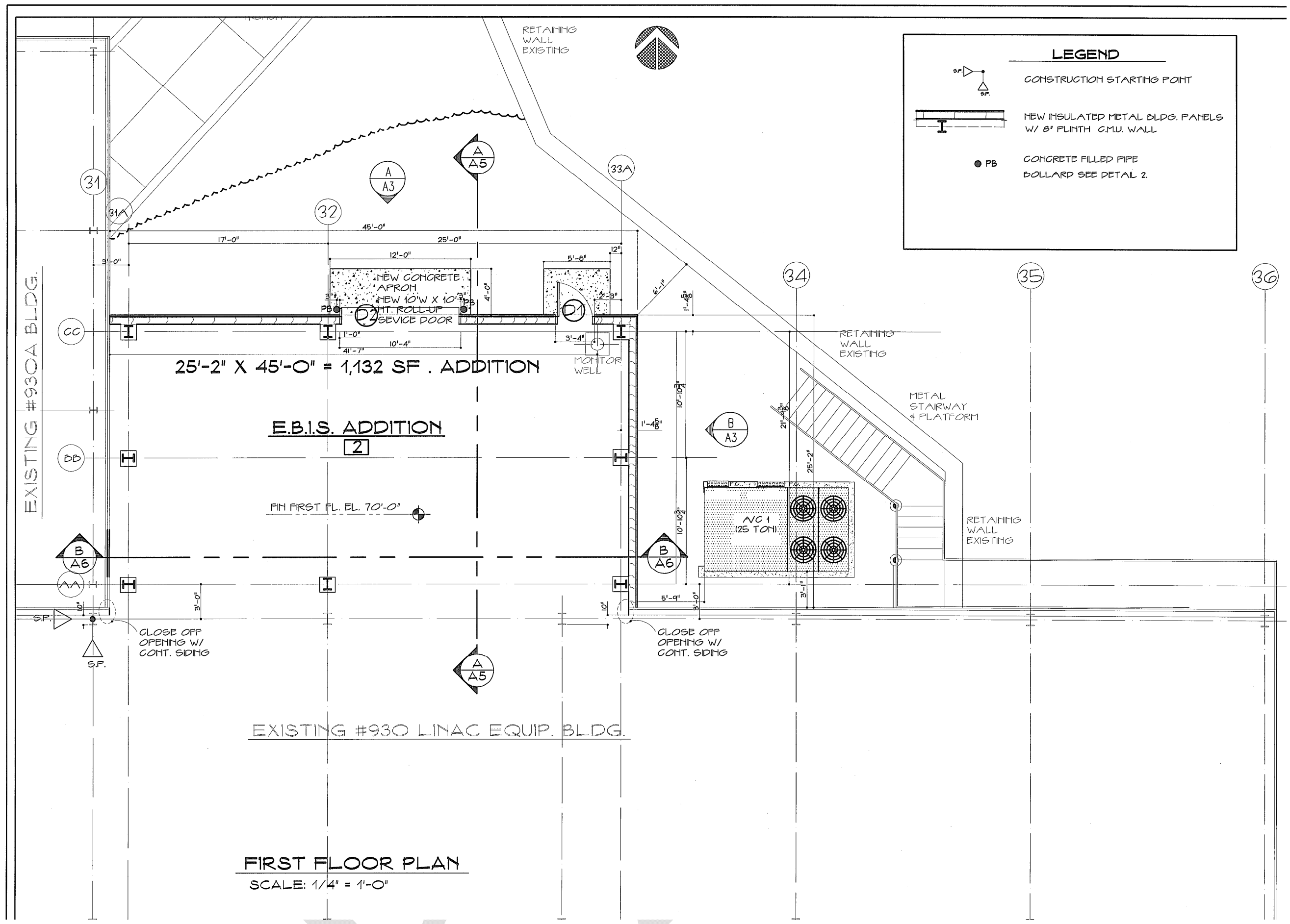
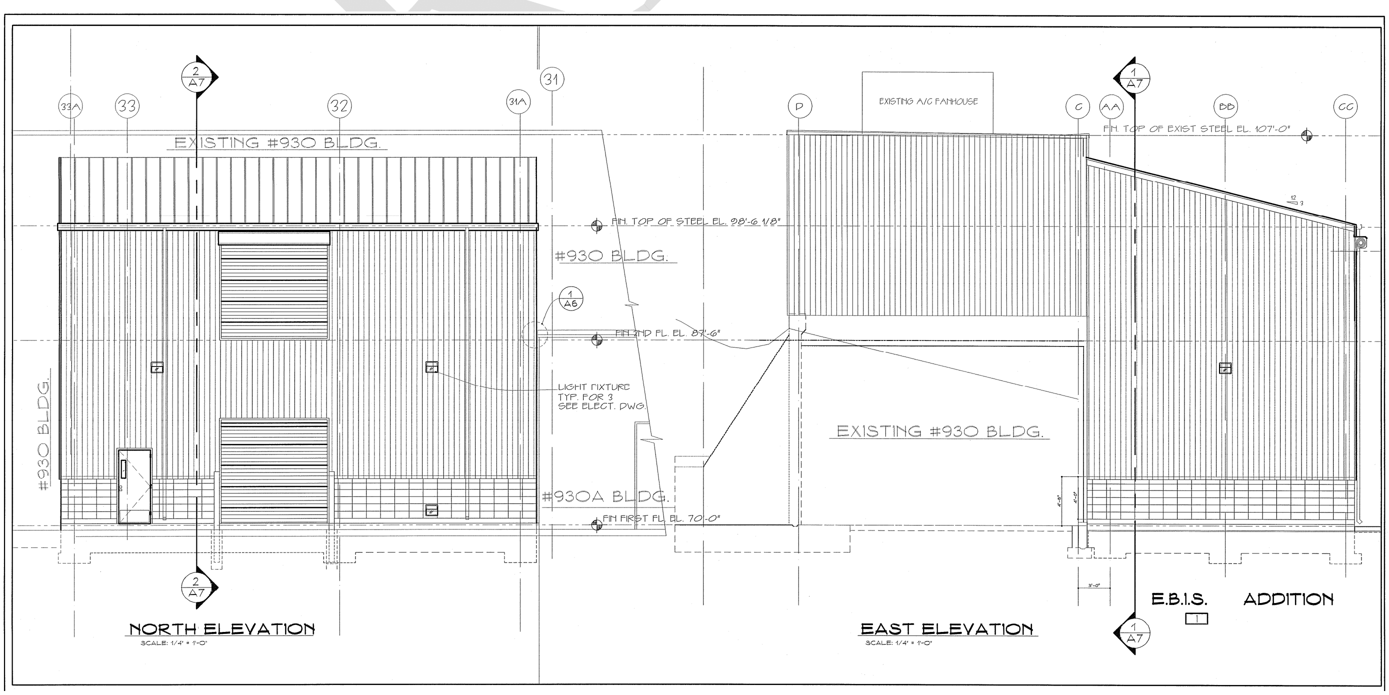


Figure 3.2.b EBIS Pre-Injector Addition at Linac Building 930





3.2. EBIS Pre-Injector Characteristics Related To Safety

The safety characteristics in bullets below are described in more detail in the sections that follow. The specific EBIS characteristics related to safety include:

- A formal conduct of operations program that uses written approved procedures
- Work planning
- Authorizations for all work
- Safety features and safety markings (e.g., pressure relief, UL marks, etc.)
- Safety limits for routine operations
- Radiation shielding to control routine and fault levels of ionizing radiation
- Magnetic field shielding and warnings to protect workers
- Configuration controls for EBIS Pre-Injector drawings and equipment locations
- Formal design reviews
- Formal safety reviews
- Containment of RF within enclosures
- Continuous monitoring and alarms for fire, smoke, ODH, water leaks
- Certified hoists, cranes and rigging equipment
- Certified materials, welds and welding inspectors for pressurized equipment
- Trained and qualified staff for accelerator operations and maintenance activities
- Testing and calibration of safety related equipment and monitors

3.3. Management Methods Used In Operating the EBIS Pre-Injector

The C-A Department 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 proton/heavy ion 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-A Department is under a formal Conduct of Operations Agreement with the Department of Energy.[7] The documentation used to comply with this agreement is the C-A Department Operations Procedure Manual, called the Collider-Accelerator OPM, which specifies key procedures, chain of command, authorized personnel and other operational aspects.[8] The EBIS Pre-Injector falls under the C-AD Conduct of Operations Agreement, and operations and maintenance procedures for the Pre-Injector are in the C-AD OPM. The process used to assure that personnel are qualified in safe operations is an extensive training program, including formal examinations, to certify operational qualifications where appropriate.

Only authorized Department personnel operate the Pre-Injector. Direct daily supervision of shift operations is the responsibility of the on-duty C-A Operations Coordinator. All Operators are authorized to shut down the EBIS Pre-Injector whenever an unsafe condition arises, or whenever they think that continued operation is not clearly safe. Operators are also

[7] Conduct of Operations Agreement
[8] Operations Procedure Manual

authorized to take any other corrective safety- or environmental-protection-action as indicated in the Collider-Accelerator OPM. All scheduled operational-related maintenance is done with the authorization of the C-A Work Control Coordinator, with the work-control authorizations prescribed in the Collider-Accelerator OPM and with the knowledge of the on-duty C-A Operations Coordinator.

Role, responsibility, accountability and authority statements (R2A2s) establish the expectations and duties of C-AD managers, supervisors and workers for carrying out operations and maintenance work consistent with external and internal requirements.[9] Further description of management methods and the safety and environmental protection organization within C-AD may be found in the C-AD Safety Assessment Document.[10]

9 R2A2 Subject Area
10 C-AD Safety Assessment Document

3.4. Design Criteria and As-Built Characteristics of EBIS Pre-Injector, Supporting Systems and Components with Safety-Related Functions

Design Criteria and As-Built Characteristics of EBIS Pre-Injector

All stable species from d to U are desired. Helium to U will be produced in EBIS. For convenience, deuterium beam may be produced in a simple plasma source injecting directly into the RFQ. In order to provide ions/bunch in RHIC the same as those already run, the following intensities are required at Booster input:

- Au^{32+}: $2.7x10^9$ ions per pulse or $8.6x10^{10}$ charges per pulse, which is sufficient to achieve $1.2x10^9$ ions per bunch in RHIC
- D^+: $2.5x10^{11}$ ions per pulse, which will be from a plasma source
- Cu^{11+}: $1.0x10^{10}$ ions per pulse or 1.1×10^{11} charges per pulse

Similarly, in order to provide species and intensities for NSRL matching the best previous runs, the intensities listed in Table 3.4.a are required at Booster input.

Table 3.4.a Intensity at Injection to Booster for NSRL Operations

Species	Q	Ions per pulse	Charges per pulse
C	5^+	$2x10^{10}$	$1x10^{11}$
O	8^+	$6.7x10^9$	$5.3x10^{10}$
Si	13^+	$5x10^9$	$6.5x10^{10}$
Ti	18^+	$1.3x10^9$	$2.4x10^{10}$
Fe	20^+	$1.7x10^9$	$3.4x10^{10}$

These numbers assume the expected efficiency from Booster injection to extraction of ≥ 85% for few-turn injection. One needs ≤ $1.1x10^{11}$ charges per pulse in all cases for the beams to be produced by EBIS. With a trap capacity in the EBIS of 10^{12} charges, these intensities are readily achievable.

Pulse width is variable between 10 and 40 µs. This allows 1-4 turn injection into the Booster. This simplifies the injection, and should greatly reduce the sensitivity to small beam losses at injection, which could otherwise lead to a pressure bump resulting in further beam loss.

The pulse width will allow for 1 to 4 turn injection at the Booster. It may also be possible to extract ions from the source in short bursts to match directly the Booster RF buckets. With the Booster RF harmonic number 4 or 6, this would require a bunch length about 1.23 µs or 0.83 µs, respectively. The energy spread and the transverse emittance should be unchanged with this "bunched" beam.

The beam energy spread at the exit of the Linac is ±20 keV per amu for Au^{32+}, which is reduced by a debuncher to ± 2 keV per amu. This is crucial for keeping the Booster beam longitudinal emittance small. The transverse profile of the beam will be Gaussian-like.

The pulse repetition rate is 5 Hz. This keeps overall RHIC fill times to only a few minutes.

The kinetic energy per unit mass at injection to Booster is 2 MeV per amu. This keeps velocities of different ion species constant. Present TVDG injection is at 0.92 MeV per amu for Au. At this energy, there is a significant beam loss due to electron capture by ions during Booster injection. By raising the injection energy to 2 MeV per amu, the electron capture cross section of the ion is reduced by a factor of 20-40. In addition, the higher energy reduces the space charge tune shift at injection. At even higher injection energies one would approach the voltage limit of the inflector, and losses due to further ionization would begin to become important.

The switching time between two species will be 1 second. There are presently several operating scenarios for RHIC and NSRL, depending on, among other things, whether either is running alone, or the two are running concurrently. To allow operation with the desired flexibility, the new pre-injector must be able to switch beam species and transport line rigidity in 1 second.

Table 3.4.b gives performance specifications for the new pre-injector; performance objectives that relate to radiation protection. This required performance is achieved with the EBIS source, followed by an RFQ and short Linac.

Table 3.4.b Radiologically Important Performance Parameters for Injection into Booster

Quantity	Au^{32+}	D^{+}	Unit
Particles per pulse	3	250	10^{9}
Kinetic energy per amu	2	2	MeV/u
Ion velocity relative to speed of light	0.0652	0.0652	
Pulse width	10 to 40	10 to 40	µs
Energy spread per amu	±2	±3	keV/u
Pulse repetition rate	5	5	Hz

Typically, photons and electrons less than 7.5 MeV are not likely to induce radioactivity in any target except beryllium (1.66 MeV) or deuterium or tritium (a few hundred keV). It is noted that beryllium, tritium and deuterium are not used in the components or walls of the EBIS Pre-injector, thus, induced radioactivity from beam induced 2 MeV photons or electrons is unlikely.

Neutrons from heavy ion beams are possible and at the ion currents planned, neuron dose equivalent is significant for the less massive ions. At 2 MeV per amu, ions more massive than copper are unlikely to penetrate the coulomb barrier since the coulomb barrier increases dramatically for high Z ions.

It is noted that the mass number of the target atom has little impact on the neutron yield. Table 3.4.c shows the neutron dose equivalent from an unshielded source of 2 MeV per amu ions after hitting a thick target. The beam currents used in the calculation are similar to those planned for the EBIS Pre-injector. The physical location of concern is the IH linac where the lighter heavy ions gain enough energy to penetrate the coulomb barrier of target atoms and cause nuclear reactions that release neutrons. If there were no beam losses, then neutrons would not be a concern; however, there are always beam losses and at these beam currents, even small losses may produce measurable neutrons.

The maximum possible neutron dose equivalent is shown as a function of angle between the beam axis and the dose point. A parameter f(θ) was used to show the angular distribution of neutron dose equivalent from this point source. A value of γ equal to 1 was chosen to represent a somewhat isotropic distribution at low energy that is slightly forward peaked; that is $f(0^o)/f(90^o)$ is 1.5. [11]

Full beam loss at exit of IH Linac, 2 MeV per amu

γ = 1.00E+00

Neutron Dose Equivalent Rate, mrem/h at one meter

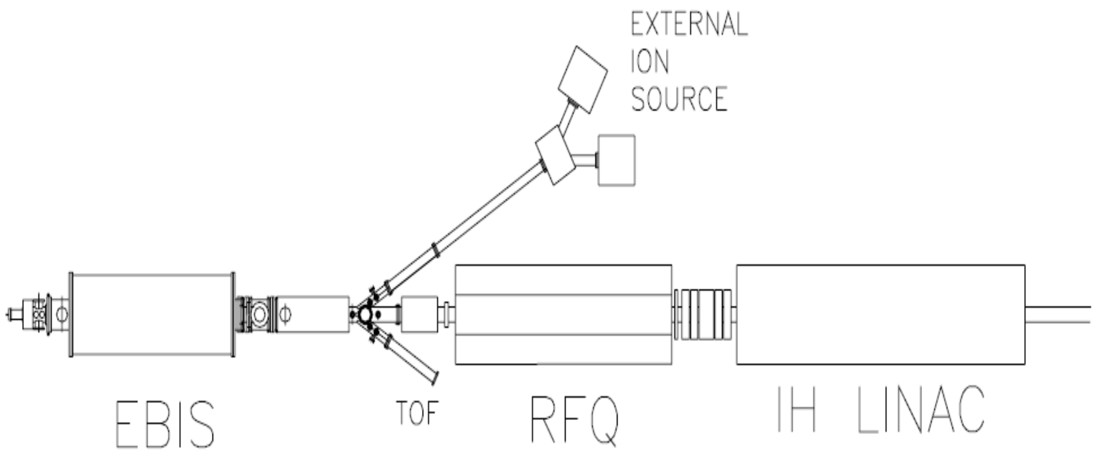
θ	f(θ)	Deuteron	C	Cu	Au	U
0.00E+00	1.15E-01	8.69E+06	3.89E+03	6.44E+00	5.38E-02	3.37E-02
4.50E+01	9.28E-02	7.03E+06	3.15E+03	5.20E+00	4.34E-02	2.72E-02
9.00E+01	6.66E-02	5.04E+06	2.26E+03	3.74E+00	3.12E-02	1.95E-02
1.35E+02	5.75E-02	4.35E+06	1.95E+03	3.22E+00	2.69E-02	1.69E-02
1.80E+02	6.38E-02	4.83E+06	2.16E+03	3.58E+00	2.99E-02	1.87E-02

3.5. EBIS Subsystems

The major structural components will be installed in the EBIS facility in Building 930. The conceptual layout is shown in Figure 3.5.

Figure 3.5 Conceptual Layout of the EBIS Pre-Injector

[11] F. Clapier and C. S. Zaidins, "Neutron Dose Equivalent Rates from Heavy Ion Beams," Nuclear Instruments and Methods 217 (1983) 489-494

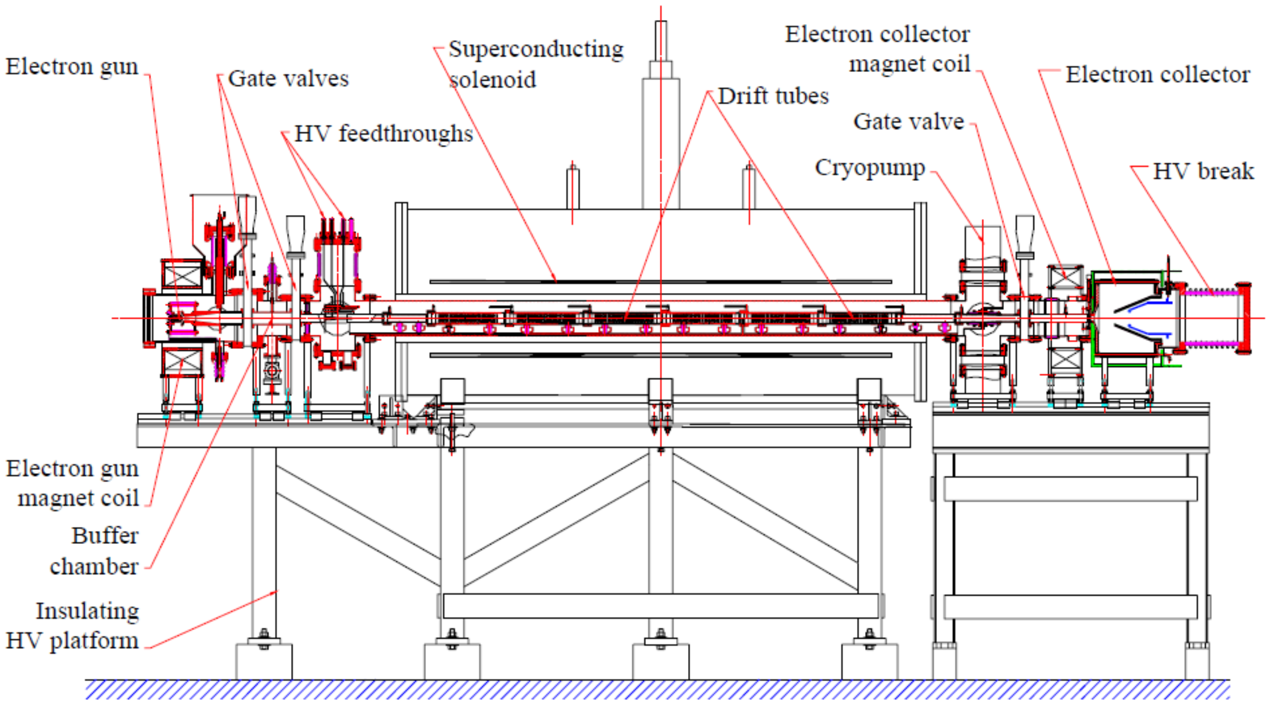


3.5.1. Hazards from EBIS Pre-Injector

3.5.1.1. Superconducting Solenoid

The superconducting solenoid (Figure 3.5.1.1) is a major element of EBIS and its function is to focus the electron beam generated in the electron gun and maintain its diameter in a region of the ion trap. No shielding is planned for the solenoid in order to enable use of its magnet field "tails" for the electron beam transmission in areas where use of other coils is difficult. The solenoid is located on the EBIS platform and it requires minimum maintenance for refilling of cryogens.

Figure 3.5.1.1 Detailed Schematic of the EBIS



3.5.1.2. Electron Gun

The EBIS electron gun generates a 10 A, 20 keV electron beam (~575 A/cm^2) used for the ionization and confinement of ions in a trap. The cathode material (Ir-Ce) provides high emission current density with a lifetime of several thousand hours. The electron gun chamber is separated from the rest of the EBIS by two gate valves, which in a case of gun failure allows replacement of whole gun unit by a new one without venting the gun chamber and venting only small buffer volume between gate valves.

3.5.1.3. Drift Tube and Chamber Structures

Drift tubes are installed along the EBIS axis to control ion trap operation and propagation of the electron beam. Drift tubes are electrically isolated from the ground and connected to the external power supplies via electrical feed-throughs in a vacuum jacket. Vacuum chambers form a vacuum envelope around the EBIS with the pressure of residual gas in the range of $1x10^{-10}$ Torr. Three gate valves separate different parts of the EBIS for maintaining high vacuum in parts that are not vented during modification or repair.

3.5.1.4. Stands and Platform Hardware

This includes the mechanical support structures for the EBIS, the electron gun, the LEBT line, and the external ion sources. It also include the 100 kV insulating platform for the EBIS source and its associated power supplies, as well as the electrical system required to put a ramp on the EBIS trap electrodes for fast ion extraction.

The ion beam energy per unit mass is 17 keV/u at the output of EBIS.

3.5.2. Low Energy Beam Transport (LEBT) and External Ion Source

These are the beam lines attached to the EBIS.

3.5.2.1. LEBT

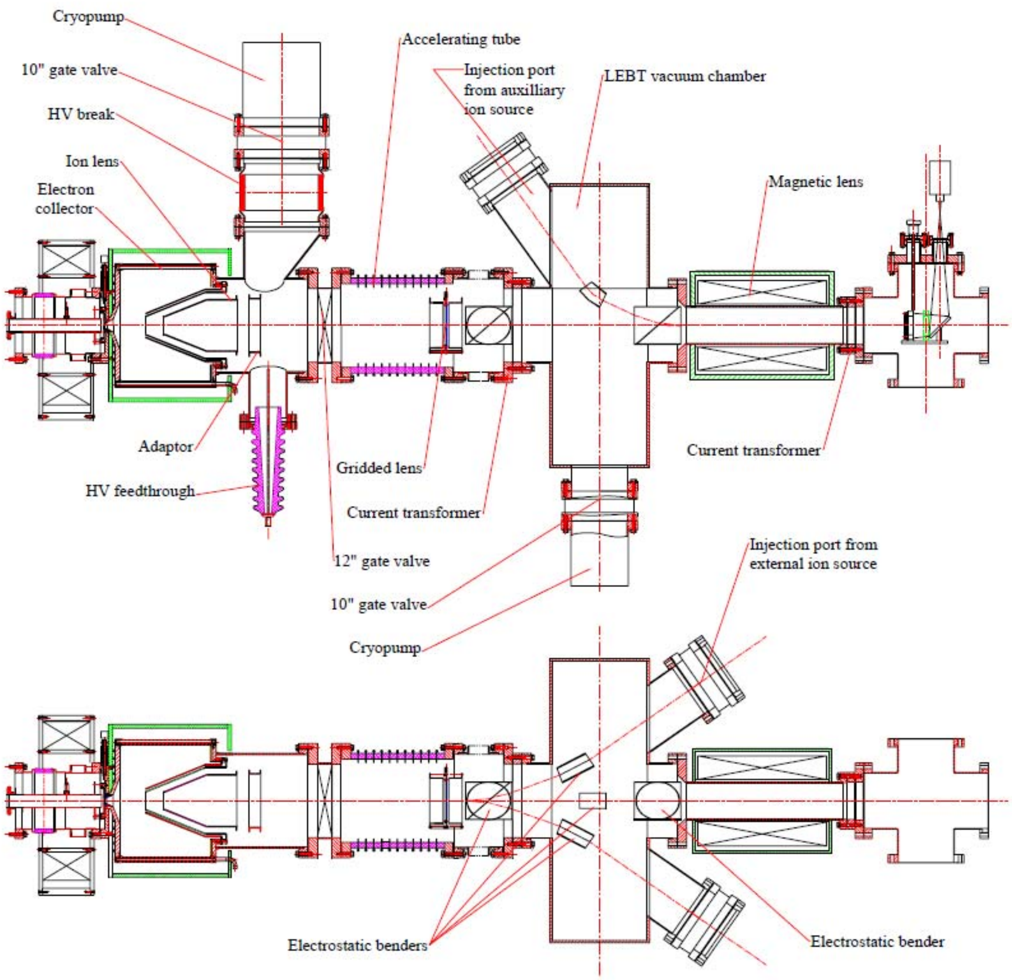
The Low Energy Beam Transport (LEBT) transports the beam from the EBIS and matches it to the RFQ. The LEBT is a transitional portion of the pre-injector and it:

- Transmits and forms the ion beam for the injection into RFQ

- Transmits the ion beam from the external ion injector into the EBIS
- Is used for diagnostic measurements of the ion beams
- Is used for vacuum pumping of the electron collector

The LEBT consists of two vacuum chambers separated by a gate valve; it contains optical electrostatic elements (deflectors, lenses), magnetic lenses for focusing the ion beam into the RFQ and diagnostic elements. See Figure 3.5.2.1. (NEEDS UPDATING)

Figure 3.5.2.1 LEBT Design



3.5.2.2. External Ion Source

External ion sources seed the EBIS with primary low charged ions of the selected species. A set of two or more ion sources generates low charge state ions for injection into EBIS. This also includes ion optics, a switching station for electronically selecting the desired ion species for ion injection, ion current monitors, vacuum system and power supplies.

3.5.3. RF Structures

Resonant cavities are used to accelerate or decelerate, for bunching, the ion beam. When radiofrequency power is fed into these resonant cavities, the appropriate electric fields for acceleration or deceleration are produced.

3.5.3.1. RFQ

The Radio Frequency Quadrupole (RFQ) is a resonant structure in which four long, continuous vanes or rods, machined with precise modulations and configured in a quadrupole geometry, provide bunching, focusing, and acceleration of the injected ion beam. This type of structure is able to provide efficient rf acceleration at the low energies ion beams have when initially extracted from an ion source. A 4-rod RFQ operating at 101.28 MHz is used.

The beam energy per unit mass is 300 keV/u at the output of the RFQ.

3.5.3.2. Linac

The Linac is a resonant structure, which generates time dependent axial electric fields to accelerate ions. When the rf field direction is reversed, the ion bunches are shielded from the decelerating fields by internal drift tubes. An "Interdigital-H"- type Linac operating at 101.28 MHz is used.

The beam energy per unit mass is 2 MeV/u at the output of the Linac.

3.5.3.3. Buncher Cavities

A resonant cavity in which the time dependent field in a gap is adjusted to decelerate the front of a beam bunch arriving at the gap, and accelerate the back of the bunch, so that all particles in the bunch arrive at a downstream point more closely spaced in time. By changing the phase of the cavity by 180 degrees relative to the bunch, it can be used to remove energy spread in the beam ("debuncher") instead.

3.5.3.4. EBIS Control System

Networked, front-end interfaces are connected via Ethernet to control console workstations and central C-AD servers. Custom application software was provided as needed, but extensive re-use was made of existing software designs with EBIS database additions.

3.5.3.5. Beam Diagnostics and Instrumentation

3.5.3.5.1. Faraday Cup

A fully destructive measurement is made when a detector head is plunged into the beam path to collect the entire ion beam. The captured charge is measured as a current in the processing electronics. Several types of detector heads are employed depending on the characteristics of the desired measurement.

3.5.3.5.2. Current Transformers

A ferrite toroid wound with many turns of signal wire is positioned around a ceramic break in the beam transport, all enclosed in a protective shroud. This is used as a non-destructive technique to measure the ion beam current characteristics with respect to time. A separate set of wire turns on the toroid is used for injecting a calibration signal.

3.5.3.5.3. Profile Monitors

Transverse beam profiles are measured by plunging an array of thin wires into the beam path. Each of the wires collects the charge from the small portion of the ion beam it intercepts; this charge is detected as a current in the processing electronics.

3.5.3.6. Magnet Systems

3.5.3.6.1. EBIS Warm Solenoids

The EBIS warm solenoids consist of three solenoid magnets. The electron gun solenoid (15.24 cm long, 0.22 T) is designed with water-cooled hollow conductors, pancake-style coils and no iron return. The electron gun coil provides the necessary field for proper electron beam launching and transport. The electron collector solenoid (12.7 cm long, 0.15 T) is similar in design to the electron gun solenoid. The electron collector solenoid focuses the beam to allow for proper electron collector operation. The remaining magnet, the LEBT solenoid (24.1 cm long, 1.25 T), is a pulsed solenoid located directly in front of the RFQ. The LEBT solenoid focuses the EBIS beam into the RFQ. The design of the LEBT solenoid uses pancake coils with a laminated iron return.

3.5.3.6.2. MEBT Quadrupoles

The EBIS MEBT quadrupole magnets (10 cm long, 33 to 38 T/m) are used to provide the necessary focusing for beam transport between the RFQ output and the Linac input.

3.5.3.6.3. HEBT Dipoles

The HEBT dipoles (10 cm gap, 1.3 T) are two similar 73° bending dipoles. The basic design of the dipole is a C style with the open end facing the outer curve. The magnets are constructed of laminations of different sizes that produce the required bend shape. The magnet coils are made of water-cooled hollow copper conductor.

3.5.3.6.4. HEBT Quadrupole Magnets

The HEBT quadrupoles (20.32 cm long, 1 to 5 T/m) are air-cooled Danfysik magnets. These magnets will allow switching of values in ~ 1 second for running of different magnetic rigidity beams.

3.5.3.6.5. Linac Quadrupole Magnets

The Linac quadrupoles are 9.2 to 16.2 cm long with gradients of 42 to 44.5 T/m.

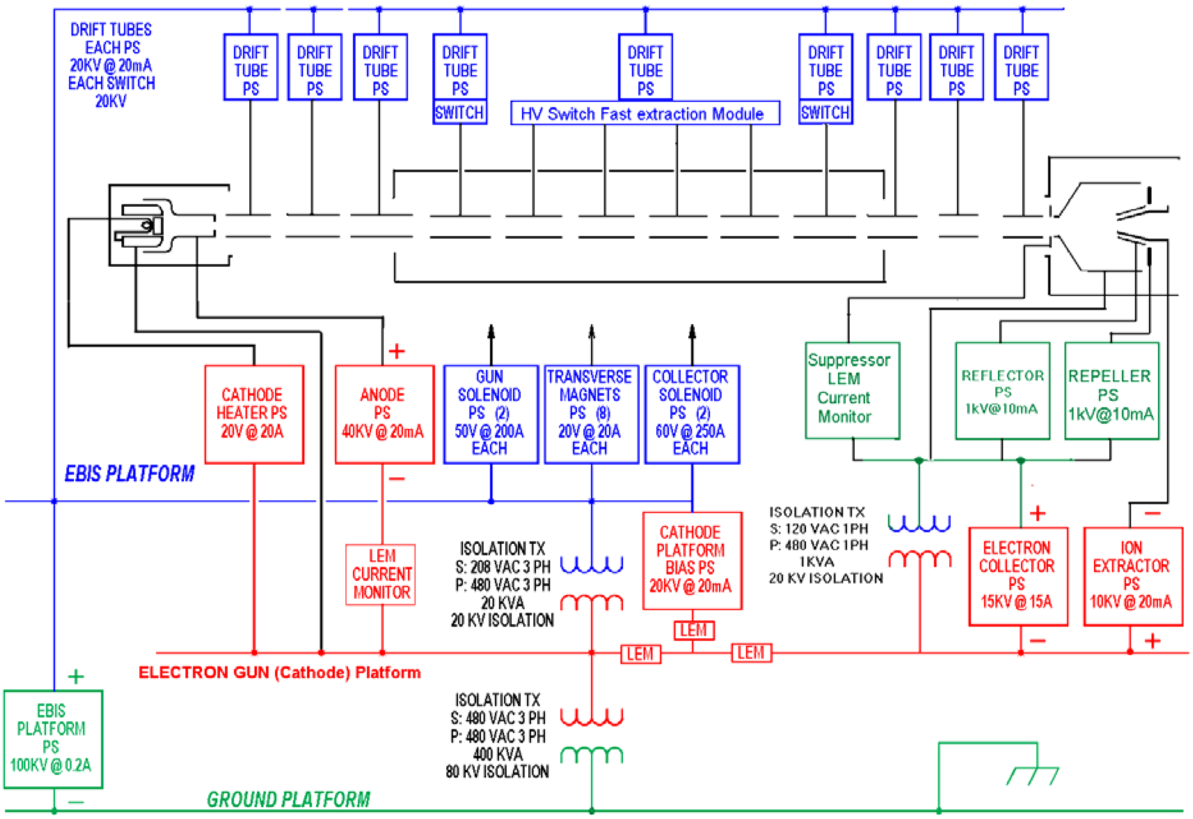
3.5.3.7. Power Supply Systems and the High-Voltage Platform

The high-voltage platform supports the electron gun, 14 drift tubes, the superconducting solenoid, the electron collector, and associated pumping systems and magnets required to operate the EBIS. The entire platform is designed to pulse at 100 kV above ground at a 5 Hz repetition rate. The more than 20 power supplies required to energize the equipment located on the platform are also required to float at approximately 100 kV above ground. These power supplies, as well as the EBIS platform, are located within a locked and grounded metal fenced barrier or “cage”. All power supplies are air cooled but some other components are water cooled. Water cooling of platform components is achieved by a closed loop de-ionized water system operating at platform potential. Sufficient water cooling of the Electron Gun and Collector, for example, is critical in order to avoid serious damage to the electron collector surface, which must dissipate 485 W/cm^2.

Electrical power to the platform is supplied by two 200 kVA, 3 phase, 100 kV isolation transformers and one 30 kVA transformer. One 200 kVA units is 480 V /480 V, the other is 700 V/12 kV, and the 30 kVA unit is 480 V/208 V. This power is distributed to the various platform loads via a three phase distribution network. Total power required by platform components in the present configuration is slightly lower than 400 kW.

Hazards include the shock hazards inherent with the 100 kV pulser as well as those associated with the various platform power supplies rated from 40 kV down to 50 volts. There is also an arc flash hazard associated with the secondary side of the 200 kVA isolation transformers. The control of the hazards is via the high voltage "cage" surrounding the floating equipment. The cage is locked via a captive key system (Kirk Locks), which precludes entering the area unless the high voltage platform pulser is propEBIS Pre-Injectory locked and tagged out. Opening the cage will also cause a grounding relay to de-energize automatically grounding the floating deck. In addition, procedures will be put into place that require grounding the platform with clamped conductors to building ground whenever work is performed within the caged area. Any work done inside the caged area with the pulser propEBIS Pre-Injectory locked out and the floating system grounded will be covered by standard lock out tag out procedures. The arc flash problems associated with switching high power 480 volt systems will be mitigated by the use of appropriate PPE worn by fully qualified employees. The floor of the deck above the pulser is a grounded metallic grid. This grounded deck mitigates the shock hazard from the floating deck below but would allow small debris from the work done on the equipment on the second floor to fall on the high voltage equipment. A fluid leak from the water cooled equipment on the second floor could easily drip on the pulsed high voltage equipment below. While this is not a safety hazard it could certainly damage expensive equipment.

Figure 3.5.3.7 Schematic of EBIS Voltage Platforms



Power supplies used to support EBIS:

- Solenoid, cathode, cathode heater, collector and grid supplies
- Platform bias supplies and the transformers to isolate them
- Drift tube supplies, Behlke switches, and transverse magnetic supplies

Power supplies used to support two external ion sources, the transport from the ion sources to the LEBT, and the LEBT itself:

- Heater, arc pulser and extractor power grid supplies
- Platform bias supplies and the transformers to isolate them
- Supplies for electrostatic and electromagnetic steering elements and lenses

- Mass analyzer and focusing solenoid power supplies

Power supplies used for the MEBT, Linac and HEBT:

- Pulsed quadrupole magnets and steering magnet power supplies
- Linac drift tube quadrupole magnet power supplies
- Pulsed bending magnet power supplies

3.5.3.8. RF Systems

The final high-power rf amplifier stages are powering the RFQ, Linac, and three bunchers. This includes the coaxial transmission line connecting the amplifier outputs to the rf cavities. Low power RF systems provide the phase and amplitude controls for the high power rf systems, and frequency control for the resonant cavities. Vacuum pumps are used to evacuate or pump down a vacuum chamber from atmospheric pressure to the desired high vacuum or ultra-high vacuum range.

3.5.3.9. Vacuum Systems

Vacuum systems are pipes or chambers that have vacuum-level pressure inside and provide a path for the ion to be transported, as well as provide a housing for special components inside the vacuum system. A PLC-based control system is used to monitor and control the vacuum system and components such as gauges, pumps and valves. Vacuum valves are manual or pneumatically operated valves used to isolate vacuum pumps and/or a section of the beam line from another section or vacuum chamber.

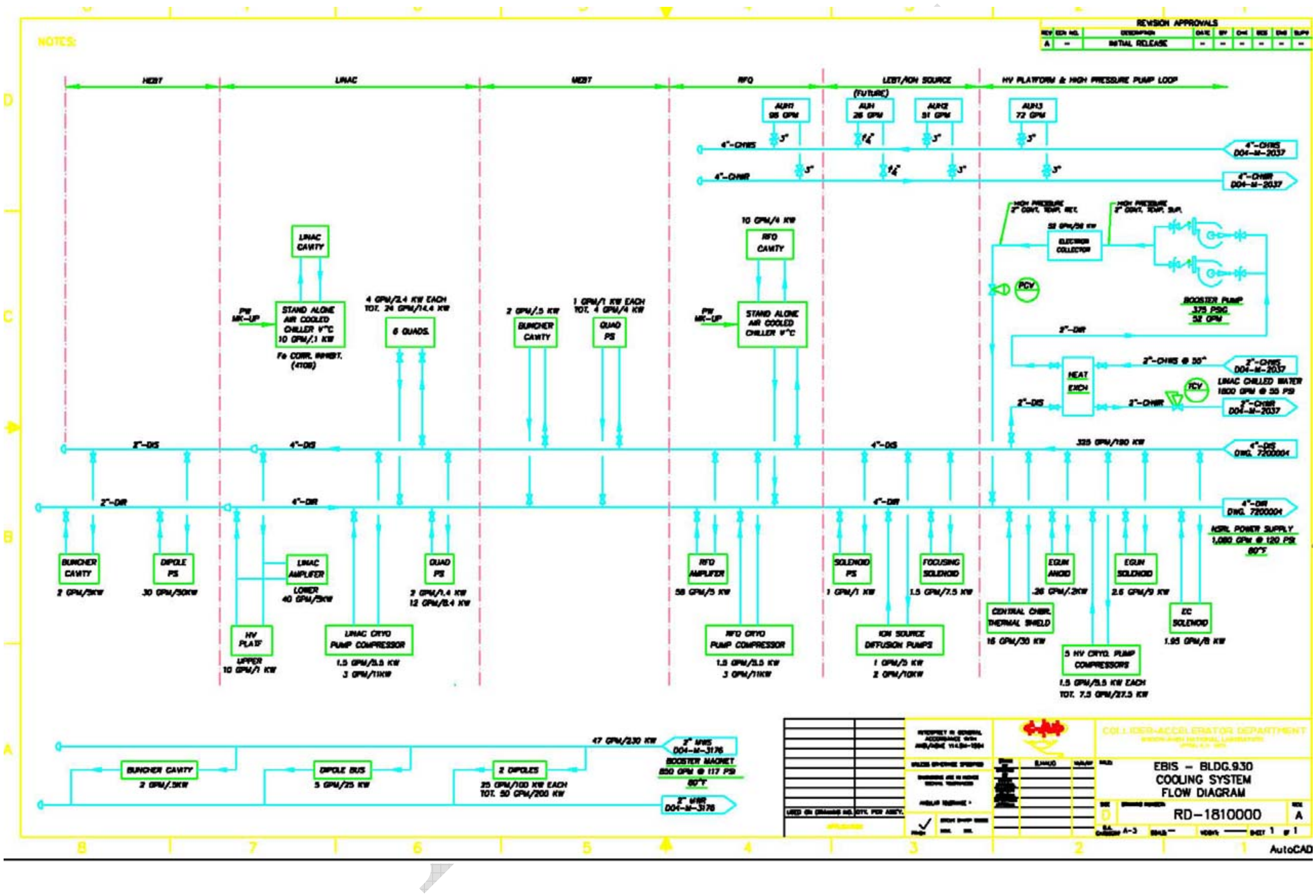
3.5.3.10. Cooling Systems

The cooling system is comprised of three separate and independent closed loop systems that will run off the present Linac chilled water system and dissipate heat into the existing Linac cooling tower. Each system consists of individually skid-mounted components: a pump/motor, filter, heat exchanger, expansion tank, temperature and pressure control valves, and water treatment as required. The active on-line deionized water controls on two of the systems maintain the required resistivity. The exception is for the rf structures, which will have a 4109 iron corrosion inhibitor control system. Figure 3.5.3.10.a shows the EBIS Pre-Injector Cooling System Flow Diagram.

A chilled water source is required to supply the necessary 70 ^{o}F temperature. The existing Linac chilled water system is used.

It is noted that operators are knowledgeable of processes and safety that affect operations and are able to analyze off-normal situations and take action to correct the causes. In this case, operators are trained to look for unexpected conditions such as water leaks and to check local status panels and local alarms when on tour. Operators are trained to respond to alarms in a timely fashion, taking reasonable actions. For example, see C-AD OPM 2.19, "Response to Water Makeup Alarms."

Figure 3.5.3.10.a EBIS Pre-Injector Cooling System Flow Diagram



3.5.3.11. Modifications to Access and Egress, and Modification to Power Distribution

A new access port for the EBIS beam line was installed through the earth shielding from Linac to the Booster. See Figure 1.2.b. A new exit door from the upper equipment bay at Linac exits onto a staircase on the Booster berm, approximately 20 feet into the Booster fenced enclosure. See Figure 3.2.b.

Two 8" vertical ports through the top of the Booster tunnel in the "C" area were installed to power the dipoles in the EBIS beam line. Additionally, electrical modifications involved the relocation of existing power and tray in the Linac area where the EBIS beam line is installed. Radiation safety was examined by the Radiation Safety Committee for all new penetrations.

3.5.3.12. Installation Work

The major systems and components of the EBIS were installed in Building 930 and the new addition, including structural components, control systems, diagnostic and instrumentation systems, magnets, power supplies, RF systems, vacuum systems, and cooling systems. The installation effort included minor additions or changes to the building and facility necessary to accommodate these systems and components. The major structural components installed inside the building were the EBIS, RFQ and Linac. Other components included smaller devices located in the LEBT, MEBT and HEBT beam transport regions, such as auxiliary ion sources, bunchers, electrostatic beam transport devices and beam monitoring devices. Installation included:

- Controls for the entire project.
- Checkout of all diagnostics in the beam lines
- Magnet systems, which are dipole, quadrupole, solenoid and steerer magnets

- Power supplies
- Connection of power from breaker boxes to the supplies
- Connections from the power supplies to the element
- Beam pipes, chambers, pumps, and valves
- Leak checking and bake out of systems

3.5.4. Hazards Associated With EBIS Pre-Injector Installation and Operation

- There are chemicals or chemical wastes used, stored or generated
- There are flammable or combustible gases, liquids or solids, including solvents
- The operation involves the use, storage or generation of caustic/corrosive chemicals or wastes
- The operation involves the use of hydrogen (deuterium) gas
- There are non-radioactive air emissions or effluents
- Waste (radioactive, hazardous, mixed, sanitary, etc.) is produced as a result of this operation
- Personnel work on energized systems greater than 50 V but less than 600 V (verification step in Lockout Tagout or operation of breakers or disconnects)
- The operation involves use of heavy metals such as gold and uranium
- There are radiation generating devices
- Use of uranium beam may result in radioactive air emissions from the vacuum pumps
- Some equipment was non-commercial and is not listed by a Nationally Recognized Testing Laboratory
- This system/operation involves a cryogenic system and dewar installation.
- There are sources of potential and kinetic energy (hydraulic, pneumatic, thermal, mechanical)

- Radiofrequency radiation is generated
- High voltage and high current are used
- This equipment/operation produces magnetic fields greater than 4 Gauss (0.0004 T)
- Because of cryogenics, there any possibility of creating an Oxygen Deficient Atmosphere
- Operation requires work outside normal working hours
- Radioactive materials are handled used and stored
- Operation includes the use of hoist, crane, forklift and rigging
- Operation requires elevated work
- Some equipment operates at pressures above 15 psig or under a vacuum
- Operation includes the use of typical shop equipment
- There are surface temperatures less than 0 deg F and greater than 150 deg F
- Noise levels may be between 85 dBA and 100 dBA
- Vacuum vessels may be backfilled with cryogenic liquids and raised to high pressures
- Vacuum pumps may accumulate U atoms
- Vacuum vessels can collapse
- Power distributed to the building and within the building was modified and errors could have occurred
- The building structure was modified and errors could have occurred

3.5.5. Controls Associated With EBIS Injector Installation and Operation

- Requirements in the Working with Chemicals SBMS Subject Area will be met; this would apply to gases, uranium or any other source materials to be used
- All work is planned

- All Personal Protective Equipment requirements are listed in work planning documents
- A baseline industrial hygiene monitoring program is used for carcinogen monitoring and other chemical hazards
- When working with deuterium gas, special requirements apply; at a minimum in the event of total loss of containment, the percent of deuterium gas in the room will not exceed 0.4%. Flammability range is 4 to 75%
- Work with caustic/corrosive chemicals will be done in an area with an eyewash and shower.
- Work with heavy metals such as U foils requires special handling and training
- The Radiation Safety Committee (RSC) reviewed the penetrations into Booster and the routine operations of EBIS, and reviewed and approved shielding, fencing and intEBIS Pre-Injectorocks
- Work with radioactive materials and sources are controlled with a Radiation Work Permit
- Radioactive sources are inventoried
- Noise areas are inventoried
- Chemicals are inventoried
- Waste generators have proper training
- Operations involving air emissions or wastewater discharges was assessed to determine whether they meet current permit limits or require a permit
- All personnel working with electrical systems have Electrical Safety, Lockout/Tagout training and Personal Protective Equipment
- The Chief Electrical Engineer has ensured devices not commercially available are examined by trained Electrical Equipment Inspectors
- Hoist, cranes or rigging equipment have annual inspection tags

- Workers are trained for safe operation of forklifts, powered trucks, platform lift trucks and motorized hand trucks, and they perform a pre-use inspections
- Ladders are not be wooden, scaffolding is be reviewed by the C-AD ESH Coordinator and elevated work requires fall protection and/or a fall protection plan
- Pressure systems have been reviewed by the BNL Cryogenic and Pressure Safety Subcommittee, and appropriate controls are in place (pressure reliefs, welding tests, materials certifications, etc.)
- Use of inert cryogens in the EBIS areas underwent Oxygen Deficiency Hazard review
- Handling cryognic liquids requires training and Personal Protective Equipment
- Electrically powered hand tools are double insulated and plugged into grounded systems
- All sources of stored energy are locked out or disabled prior to working on systems
- Non-ionizing radiation sources (NIR) sources (rf structures) are listed on the C-A NIR inventory and require measurements to be taken
- Any workers with pacemakers or medical implants require training, and are not exposed to fields greater than 5 Gauss
- Air monitoring is required for lead handling of more than 30 minutes
- Surface with temperatures less than 0 deg F or greater than 150 deg F are labeled
- The operation procedures for the EBIS Pre-Injector sub-systems are incorporated into the C-AD Operations Procedure Manual
- Operational procedures were developed for normal operations, and a list of trained personnel is maintained
- An emergency procedure was developed in accordance with C-A OPM 3.0
- Workers that can be potentially exposed to excessive noise are monitored for a hearing loss

- Noise Areas are posted and PPE is available at entrances
- Certain types of elevated work requires fall protection
- Pressure systems that operate at greater than 15 psig are reviewed and are in accord with ASME Codes
- Vacuum spaces that can be backfill pressurized are fitted with burst disks or relief valves
- Vacuum pumps emissions and vacuum pump oil are monitored for radioactivity
- Personnel using carcinogenic chemicals are enrolled in the carcinogen medical monitoring program
- For all flammable gases and liquids, quantities are limited such that spills or releases do not exceed ten percent of the lower flammability limit for the material
- Building modifications met the Life Safety Code and Building Code of the State of New York
- AC power distribution changes to the building met the National Electric Code
- Structures supporting heavy loads or structural changes to buildings underwent review by the Plant Engineering Division and the C-AD Chief Mechanical Engineer
- Electrically powered hand tools should be double insulated and are plugged into a grounded system
- Operation of the EBIS magnet systems is done using procedures incorporated into the C-AD Operations Procedure Manual

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

RF Structures

- Design reviewed by the C-AD Radiation Safety Committee
- Design reviewed by the BNL Cryogenic and Pressure Safety Committee
- Burst disks and relief valves
- Radiation shielding
- Magnetic field shielding
- Configuration controlled drawings

Cryogenic Systems

- Design reviewed by the C-AD Chief Mechanical Engineer
- Design reviewed by the BNL Cryogenic and Pressure Safety Committee
- Compliance with ODH Subject Area
- ODH Monitoring
- Ventilation
- Burst disks and relief valves
- Configuration controlled drawings

Vacuum Systems

- Design reviewed by the C-AD Accelerator Systems Safety Review Committee

Magnet and Magnet Electrical Systems

- Design reviewed by the C-AD Chief Electrical Engineer
- Ground-fault alarm system
- Equipment and cable tray grounds
- Enclosures or barriers over conductors

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
- Cooling-water leak monitoring and alarms
- Fire, smoke detection and alarm systems
- Configuration controlled drawings

Cooling System

- Compliance with ASME Piping Codes
- Cooling-water leak monitoring and alarms
- Configuration controlled drawings

3.5.6.1. BNL, C-AD and EBIS Organizational Structure

3.5.6.2. Administrative Controls for Routine Operation and Emergency Conditions

3.5.6.3. Critical Operational Procedures to Prevent or Mitigate Accidents

3.5.6.3.1. Emergency Preparedness

3.5.6.3.2. Configuration Control

3.5.6.3.3. Administrative Controls

3.5.6.3.4. Calibration and Testing

3.5.6.3.5. Radiological, Worker Safety and Environmental Programs

Integrated Safety Management is DOE's framework to integrate 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 and seven Guiding Principles. The five Core Functions focus on work planning and control, and are:

- Define the scope of work
- Identify and analyze the hazards
- Develop and implement hazard controls
- Perform work safely within controls
- Feedback and improvement

The seven Guiding Principles are DOE's core beliefs about managing safety and are as follows:

- Line Management Responsibility For Safety - Line management is directly responsible for the protection of the public, the workers, and the environment.
- Clear Roles And Responsibilities - Clear and unambiguous lines of authority and responsibility for ensuring safety shall be established and maintained at all organizational levels within the Department and its contractors.

- Competence Commensurate With Responsibilities - Personnel shall possess the experience, knowledge, skills, and abilities that are necessary to discharge their responsibilities.
- Balanced Priorities - Resources shall be effectively allocated to address safety, programmatic, and operational considerations. Protecting the public, the workers, and the environment shall be a priority whenever activities are planned and performed.
- Identification Of Safety Standards And Requirements - Before work is performed, the associated hazards shall be evaluated and an agreed-upon set of safety standards and requirements shall be established which, if propEBISy implemented, will provide adequate assurance that the public, the workers, and the environment are protected from adverse consequences.
- Hazard Controls Tailored To Work Being Performed - Administrative and engineering controls to prevent and mitigate hazards shall be tailored to the work being performed and associated hazards.
- Operations Authorization - The conditions and requirements to be satisfied for operations to be initiated and conducted shall be clearly established and agreed upon.

In addition to promoting these functions and beliefs, DOE enforces health and safety requirements using two federal laws: 10CFR851 Worker Safety and Health, and 10CFR835 Occupational Radiation Protection. The requirements in these laws have been flowed down through BNL's hierarchy of documents and practices and into EBIS's operating procedures and training programs.

The C-AD and EBIS use four voluntary programs to help meet the requirements of the laws, and to help implement the functions and support the beliefs of ISM. These programs are:

- OHSAS 18001 Occupational Safety and Health Management Systems Specification

- ISO 14001 Environmental Management Systems Specification
- Work Observation
- Human Performance

The OHSAS 18001 and ISO 14001 are third party certification programs. The certification process in general functions in the following manner. C-A Department or BNL selects a registrar to assess its management system. The certification body employs independent auditors to conduct the assessment. 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. This information is made available to the public through a listing in a register or directory, and the C-A Department is entitled to display proof of certification. Certificates of registration are typically valid for three years, although this can vary depending on individual certification body requirements. Certification bodies typically conduct surveillance audits, essentially less-detailed assessments, on a six-month or annual schedule. When the certificate of registration expires, the certification body will typically conduct a complete reassessment, or conduct an assessment that is more comprehensive than the periodic surveillance audits.

3.5.6.3.6. Records Management

4. Safety Analysis

The level of detail included was correlated with the size, complexity, hazards, potential impacts and risks associated with facility operation. The hazards analysis was 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 420.2G, 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 impacts, the impacts, 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 number of credited controls is a limited subset of the total number of controls employed for overall facility operation. Credited controls were assigned a higher degree of operational assurance than other controls.

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

4.1. Identification of Potentially Hazardous Conditions Associated With Operation

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

Table 4.2.a Calculated Radiation Levels Inside and Outside the EBIS

Description	Electron Current	Energy	Maximum Instantaneous Radiation Level, mrem/h
Inside EBIS Accelerator Room, Maximum Beam Loss (single point fault) [a]			
Inside EBIS Accelerator Room, Anticipated Beam Loss (routine loss) [a]			
Outside EBIS Accelerator Room, Maximum Beam Loss (single point fault) [b]			
Outside EBIS Accelerator Room, Anticipated Beam Loss (routine loss) [b]			
EBIS Control Room Maximum Beam Loss (single point fault) [c]			
EBIS Control Room, Anticipated Beam Loss (routine loss) [c]			

[a] at 1 foot at 0^{o} inside EBIS accelerator room
[b] at 1 foot from outer shield wall at beam height
[c] at 1 foot from penetration into EBIS Control Room

4.3. Selection of Control Measures That Reduce Risks to Acceptable Levels

4.4. Listing Of All Credited Engineered and Administrative Controls

Table 4.4.a Summary of Credited Engineered Controls

	Credited Engineered Control	Applicable Events
1	Chipmunk-intEBISocked beam cutoff on abnormal radiation levels	Table A.6.1 Qualitative Risk Assessment – Radiation in Uncontrolled Areas Due to Electron Beam Losses
2	Access-controlled gates	
3	Ionizing radiation shielding	
4	Smoke alarm system	
5	ODH monitoring system	
6	ASME rated pressure relief valves and burst disks, ASME compliant pressure vessels and piping or equivalent	
7	Remote sub-station ground-fault monitoring system	

Table 4.2.b Summary of Credited Administrative Controls

	Credited Administrative Control	Applicable Events
1	Review of radiation safety by C-A RSC	Table A.6.1 Qualitative Risk Assessment – Radiation in Uncontrolled Areas Due to Electron Beam Losses
2	Configuration controlled ACS drawings and computer codes; annual ACS testing	
3	Configuration controlled shield drawings and calculation codes	
4	Annual fire alarm tests	
5	ODH monitor calibrations	
6	Relief valve and burst disk maintenance according to ASME standards	
7	Ground-fault alarm testing	

4.5. Description of the Maximum Credible Incident

5. Basis for Accelerator Safety Envelope

The EBIS Pre-Injector will be operated under the existing approved ASE for AGS, Booster and Linac, which was approved on July 5, 2007, or later revisions.[12] The EBIS Pre-Injector introduces no new hazards to the C-AD.

In the future, EBIS will be the source of ions for RHIC and it will be capable of producing U-238 ions. Thus, the RHIC Accelerator Safety Envelope (ASE) was reviewed for future operations with U ions. It was determined that RHIC has acceptable luminosity with U ions at the equivalent Au ion limit. Thus, U ions in RHIC would not require alteration of the ASE for RHIC.

Because of thick walls used on the rf structures (RFQ and IH-Linac), it was determined that a separate ASE is not required for the EBIS Pre-Injector as there are no Radiological Areas created from direct radiation during normal operations. Additionally, there will not be significant levels of radiation or contamination from uranium foils (~10 g) that may be present.

5.1. Connection between Engineered and Administrative Bounding Conditions and ASE

The Accelerator Safety Envelope (ASE) for C-AD facilities formally establishes the set of bounding conditions or constraints on engineered and administrative systems, within which the Collider-Accelerator Department proposes to operate all its accelerators. These constraints are based on the safety analysis documented in Chapter 4 of the C-AD Safety Analysis Document (SAD) and any relevant current USIs. The ASE assures the validity of the basic set of assumptions used in the safety analyses and helps ensure physical and administrative controls used to mitigate potential hazards are in place.

[12] ASEs and DOE Authorizations at C-AD, http://www.agsrhichome.bnl.gov/AGS/Accel/SND/asesand.htm

DOE requires adherence to the approved requirements stated in the Accelerator Safety Envelope because it is the authorization basis for all commissioning and operations activities. The ASE is a separate controlled document that must be approved by DOE. DOE approval is required for all changes to the ASE.

To understand the appropriate level of bounding information or constraints included in Sections 2, 3, 4 and 5 of the ASE, one must first understand the overall flow-down of information from the highest level constraints stated in BNL SBMS requirements to the operating-level constraints stated in the C-A Department documents such as operating procedures. This flow-down of information generally produces several levels of constraints that provide a defense-in-depth to ensure the safe and environmentally sound operations of the accelerators. The top levels of constraints are placed in the Accelerator Safety Envelope (ASE). The operational levels of constraints are established in Department level documents.

The highest-level constraints, which are termed “Safety Envelope Limits,” are documented in Section 2 of the ASE. These are the absolute limits that BNL places on its operations to ensure that the regulatory limits established to protect the environment, the public and staff and visitors are met.

The next highest level constraints are the operating limits that are used as the basis for the hazard analysis. This level of constraints is termed “Corresponding Safety Envelope Parameters,” and is documented in Section 3 of the ASE. Section 3 of the ASE identifies the critical operating parameters that ensure the accelerator and experimental operations will not exceed the corresponding Safety Envelope Limits in Section 2 of the ASE.

BNL SBMS requirements indicate that operations procedures addressing ASE-required equipment and systems should specify the minimum necessary system components and monitoring devices to allow operation, and if these minimums are not met, then alternate actions are to be specified in the procedures. C-AD lists these alternate actions in the ASE and has termed them "Authorized Alternatives." Whenever an Authorized Alternative is used at C-AD, the Department is committed to performing a critique. Authorized Alternatives are listed in Section 3 of the ASE.

Operation-level safety-related constraints may or may not be included in an ASE. In a large complex facility like C-AD accelerators, operational-level safety-related constraints are contained in controlled documents that are reviewed and updated frequently. These documents are the Collider-Accelerator Conduct of Operations document[13] and the C-AD Operations Procedure Manual.[14]

Operational-level constraints may consist of documented or measurable limits or administrative controls necessary to establish an operational margin of safety that may be more conservative than that established in the ASE. This operating margin provides a defense-in-depth approach to ensure that the Collider-Accelerator Department will operate the accelerators and experiments well within Safety Envelope Limits and Corresponding Safety Envelope Parameters agreed to by DOE in formally approving the ASE. Operational-level constraints in the C-A OPM generally address requirements for industrial safety, environmental protection, waste management, pollution prevention, radiation protection, ALARA, workplace hazardous materials monitoring, use of personal protective equipment, and occupational health and safety.

Compliance with operational-level constraints is achieved through training of personnel, self-assessment, periodic management review and each individual's commitment to adhere to requirements in procedures. Examples of operational-level constraints may be related to ASE

[13] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm C-A Conduct of Operations
[14] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/index.htm C-A Operations Procedure Manual

parameters that are physically designed into the accelerators, such as maximum beam power, maximum beam energy or maximum beam intensity. Examples of operational-level constraints are authorizations such as 1) release of an effluent to the sanitary system and 2) radiation safety check-off lists that must be completed prior to start-up of an accelerator for a particular physics program.

5.2. Summary of ASE Content

The ASE contains five sections; however only two section contain limits: Section 2 that contains the absolute limits that BNL places on its operations to ensure the Collider-Accelerator Department meets regulatory limits established to protect the environment, public and staff/visitors; and the design/operating limits used as a basis for the SAD; and Section 3 that identifies the measurable limitations on critical operating parameters that ensures the accelerator will not exceed the Limits in Section 2. The pertinent limits are reproduced here:

Applicable Section 2 Limits: Safety Envelope Limits

- Less than 25 mrem in one year to individuals in other BNL Departments or Divisions adjacent to a Collider-Accelerator Department accelerator facility.
- Less than 5 mrem in one year to a person located at the site boundary.
- Less than 1250 mrem in one year to a Collider-Accelerator Department staff member.

Applicable Section 3 Limits: Corresponding Safety Envelope Parameters

- Loss monitoring results and radiation survey results shall be used in order to maintain beam loss "As Low As Reasonably Achievable" as defined in the BNL Radiological Control Manual.

- Beam loss induced radiation within uncontrolled areas is less than 0.5 mrem in an hour and for repeated losses less than 25 mrem in a year.
- Beam loss induced radiation in a Controlled Area is less than 5 mrem in an hour and for repeated losses less than 100 mrem in a year.
- Radiological area classifications shall be in accord with requirements in the BNL Radiation Control Manual.

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

6. Quality Assurance

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

The criteria listed below are further explained in the referenced sections:

- Criterion 1- 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 EBIS Pre-Injector

The Collider-Accelerator (C-A) Department has 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 the 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 using C-AD QA implementing procedures. These procedures supplement the BNL Standards Based Management System (SBMS) documents for those QA processes that are unique to the C-A Department. 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 will be an integral part of the design, procurement, fabrication, construction and operation of the C-AD complex.

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 organizational and facility, 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 C-AD personnel have access to the 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 Standards Based Management System (SBMS) supports C-AD management's efforts to ensure personnel working within the C-AD complex are trained and qualified to carry out their assigned responsibilities. The BNL Training and Qualification Management System is implemented within the C-A Department 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 quality problems. The Department identifies, controls, and corrects items, services, and processes that do not meet established requirements. C-AD staff identifies the causes of problems, and includes prevention of recurrence as a part of corrective action planning. The Department has programs tp 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 C-A's management, staff, customers, stakeholders and regulators. 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 within the C-A Department.

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. Additionally, the C-AD specifies, prepares, reviews, approves and maintains 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.

EBIS Pre-Injector 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.

C-AD 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. C-AD 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 has determined that it is appropriate to develop internal procedures to supplement the SBMS Subject Areas. These internal procedures are bounded by the requirements established by the BNL Subject Areas.

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. Contractors and vendors are held to the same practices.

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 commingling 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 EBIS Pre-Injector 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 10 CFR 851, nationally recognized codes and consensus standards are used. When national consensus codes are not applicable because of pressure range, geometry, use of special materials, experimental restrictions, etc., then C-AD implements measures to provide equivalent protection and ensures a level of safety greater than or equal to the level of protection afforded by the 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 EBIS Pre-Injector. 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 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 also 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. C-AD 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 propEBIS Pre-Injectory 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 includes such items as: performance measures; compliance checks; effectiveness evaluations; job assessments; surveys; environment, safety and health work observations and facility observations. Strengths and opportunities for improvement are identified. Assessment results are documented and fed back to managers, and provided 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 elements 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 C-AD specific processes. 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 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-A Department 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 environment, safety and health arenas, peer review is used to evaluate and independently verify engineering design and operational implementation.

7. Post-Operations Planning

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

The following items will be recycled or reused:

- Cryogenic Systems
- Vacuum Systems
- Magnet Systems
- Magnet Electrical Systems
- Conventional Facilities
- Safety Systems

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

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

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

C-AD Records to Facilitate Post-Operations Activities at EBIS

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

8. References/Glossary/Acronyms

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

8.2. List of Acronyms

APPENDIX 1, Shielding Analyses and Information

EBIS Linac IH Cavity: X-Rays, RF Power, Sub Frame, Plungers, U. Ratzinger, IAP-ACCC-140907 Johann Wolfgang Goethe-Universitat, Frankfurt, Germany

NBS Handbook 50, Iron Equivalents (mm) of Lead at Different X-Ray Tube Potentials

Radiation Safety Committee Minutes:

#122 Meeting Date: April 12, 2006, Subject: EBIS
#127 Meeting Date: March 20, 2007 Subject: EBIS Port with Protons Injected into Booster via LtB

F. Clapier, C. S. Zaidins, Neutron Dose Equivalent Rates Due to Heavy Ion Beams, Nuclear Instruments and Methods 217 (1983) 489-494

APPENDIX 5

Qualitative Risk Assessments

Table A5-1 Vacuum..
Table A5-2 External Events ....
Table A5-3 Electric Shock/Arc Flash ....
Table A5-4 Radiation...
Table A5-5 Conventional/Industrial Hazards ....
Table A5-6 Airborne Releases...
Table A5-7 Environmental – Cooling Water Spill ....
Table A5-8 Loss of Electrical Power...
Table A5-9 Fire..
Table A5-10 Environmental – Activated Soil ....
Table A5-11 Oxygen Deficiency Hazards (ODH)……………………………………..

Table A5-1 Qualitative Risk Assessment for EBIS Pre-Injector - Vacuum

FACILITY NAME: EBIS Pre-Injector
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 C-A/industry standards 2. Vacuum and pressure systems reviewed by the C-A 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 A5-2 Qualitative Risk Assessment for EBIS Pre-Injector – External Events

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

Event	External event impacts EBIS Pre-Injector
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 2. BNL Fire Department can respond quickly to forest fire. BNL has firebreaks 3. BNL Fire Department can respond quickly to fire near EBIS Pre-Injector 4. No active systems needed to protect personnel from adverse health effects after EBIS Pre-Injector off 5. Severe weather and flooding potential is extremely low; warning of these impending hazards will allow for EBIS Pre-Injector shutdown and for personnel safety 6. 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 A5-3 Qualitative Risk Assessment for EBIS Pre-Injector – Electric Shock/Arc Flash

FACILITY NAME: EBIS Pre-Injector
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 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 A5-4 Qualitative Risk Assessment for EBIS Pre-Injector - Radiation

Facility Name: EBIS Pre-Injector
System: Areas External to Shielded Components
Sub-System: EBIS Pre-Injector Beam-line component shielding, penetration hole into Booster
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. Pre-injector beams will not penetrate vacuum pipe walls or component wall/shield materials 2. Operator / physicist training 3. Review of radiation safety design of shields and penetrations by C-A RSC 4. Radiological area postings 5. Routine area radiation surveys 6. Periodic inspection of shielding to verify integrity 7. Interlocking radiation monitor at Booster penetration			

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 A5-5 Qualitative Risk Assessment for EBIS Pre-Injector – Conventional/Industrial Hazards

FACILITY NAME: EBIS Pre-Injector
SYSTEM: Entire Facility
SUB-SYSTEM: N/A
HAZARD: Noise, Pressurized Systems, Hazardous Atmospheres, Magnetic and RF Fields, Hoisting, Rigging, Heights, Cryogenic Fluids, Chemicals, Flammable / Explosive Gases, Falling Objects, Hot Surfaces, Trip Hazards, Welding/Cutting, etc.

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 / physicist training 3. Review and audit of conventional safety issues by C-A 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			

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 A5-6 Qualitative Risk Assessment for EBIS Pre-Injector – Airborne Releases

FACILITY NAME: EBIS Pre-Injector
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 / physicist training 4. Review of accelerator modifications by C-A ASSRC 5. Review and monitoring of IH airborne hazards by C-AD ESSHQ Division 6. Meeting requirements defined by BNL SBMS 7. Environmental Management System 8. 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 A5-7 Qualitative Risk Assessment for EBIS Pre-Injector – Environmental

FACILITY NAME: EBIS Pre-Injector
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 / physicist training 4. Review of accelerator modifications by C-A ASSRC 5. Meeting requirements defined by BNL SBMS 6. Environmental Management System 7. Chemical Management System 8. Extensive groundwater monitoring well system and groundwater-sampling program 9. 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 A5-8 Qualitative Risk Assessment for EBIS Pre-Injector – Loss of Electrical Power

FACILITY NAME: EBIS Pre-Injector
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 / physicist training 3. Review of conventional safety by C-A ASSRC and BNL ESH Committees 4. Backup power supplied to required systems to reduce programmatic impact 5. EBIS Pre-Injector automatically shuts down upon loss of electrical power 6. Emergency lighting 7. BNL and EBIS Pre-Injector 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 A5-9 Qualitative Risk Assessment for EBIS Pre-Injector – Fire

FACILITY NAME: EBIS Pre-Injector
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 system 5. Design reviewed by BNL Fire Protection Engineer 6. Design meets NFPA requirements 7. Ventilation system 8. Conventional safety reviewed by C-A ESRC 9. Fire Hazards Analysis 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 (see AGS, Linac, Booster ASE).

Table A5-10 Qualitative Risk Assessment for EBIS Pre-Injector – Environmental

FACILITY NAME: EBIS Pre-Injector
SYSTEM: Soil Shielding
SUB-SYSTEM: N/A
HAZARD: Groundwater Contamination

Event	Groundwater contamination from activated soil
Possible Consequences, Hazards	Internal radiation dose, loss of regulator/public confidence
Potential Initiators	Building 930 floor cracks allow water intrusion to activated soil, excessive beam loss in unexpected locations

Risk Assessment Prior to Mitigation

Consequence	() High	(X) Medium	() Low	() Extremely Low
Frequency	(X) Anticipated High	() Anticipated Medium	() Unlikely	() Extremely Unlikely
Risk Category	() High Risk	(X) Medium	() Low Risk	() Extremely Low
Hazard Mitigation	1. EBIS Pre-Injector has a sealed concrete floor 2. Periodic B930 floor inspections 3. Beam tuning procedures to reduce soil activation 4. Operator / physicist training 5. C-AD Environmental Management System 6. Extensive groundwater monitoring well system and sampling program in place 7. Long travel time for plume to reach BNL site boundary			

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 <u>Yes</u> If No, roll up into ASE.
Is the hazard mitigation system needed for hazard control? Y/N <u>Yes</u> If Yes, need ASE requirement (see AGS, Linac, Booster ASE).

Table A5-11 Qualitative Risk Assessment for EBIS Pre-Injector – Oxygen Deficiency Hazards (ODH)

FACILITY NAME: EBIS Pre-Injector
SYSTEM: EBIS Pre-Injector 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 LESHC Cryogenic Subcommittee 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 No If Yes, need ASE requirement