C-A Unreviewed Safety Issue (USI) Form

Title of USI: Radiation Hazards from Low Mass Ions in the TTB

Description of USI (use attachments if necessary):

Deuteron & < 12 amu ion transport, see attached.

Title and Date of Relevant ~~SAD~~ SAR: TTB SAR 11-18-91

Committee Chair or ESHQ Division Head must initial all items. Leave no blanks:

ITEM	APPLIES	DOES NOT APPLY
Decision to not revise the current SAD and/or ASE at this time: The hazard associated with the proposed work or event is covered within an existing SAD and/or ASE. ~~SAD~~ SAR Title and Date: TTB SAR 11-18-91. This Form and attachments, if necessary, shall be used to document the USI until the next revision of the appropriate SAD.	ETR ETR ETR	
Decision to submit a revised SAD and/or ASE to the BNL ESH Committee* The hazard associated with the proposed work is not appropriately included in an SAD.	 ETR	ETR

Ray Karol — 11-27-01

Signature of C-A Committee Chair or C-A ESHQ Division Head — Date

Edward T Lessard — 11-27-01

Signature of C-A Associate Chair for ESHQ — Date

* USI submitted to BNL ESH Committee as per section 4.3 of TTB SAR.

Radiation Hazards from Low Mass Ions in the Tandem to Booster (TTB) Line

Unreviewed Safety Issue

Thursday, November 15, 2001

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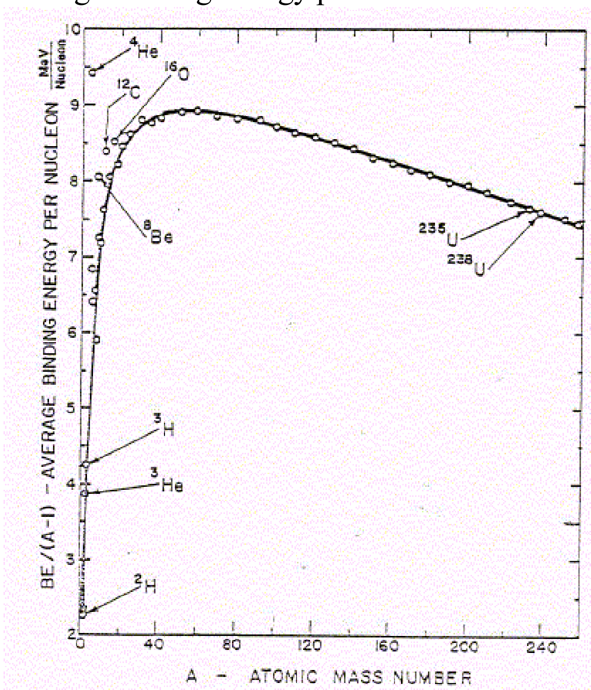
1. Introduction

1.1. Introduction to the Tandem to Booster (TTB) Unreviewed Safety Issue (USI)

This TTB USI presents a basic understanding of the mission associated with deuterons and other low-mass ions in the TTB transfer line, the protections that are afforded the public and the worker's health and safety, and the protection of the environment from radiological hazards associated with low-mass ions. It is noted that this USI supports the operation of all low-mass ions in TTB (mass<12 amu) and Tandem Van De Graaff (TVDG), not just deuterons; for example, the hazards from protons in the TTB are also bounded by this analysis. Given equal energy per nucleon and equal nucleon flux, deuterons are chosen for detailed analysis since they represent the greatest radiation hazard relative to all other low-mass ions in the Tandem accelerators and transfer line. This is because deuterons have the lowest average binding energy per nucleon (see Figure 1.1). If deuterons are energetic enough to overcome coulomb repulsion and interact with nuclei, then products of nuclear reactions can form with greater average binding energy per nucleon.

Figure 1.1 Average Binding Energy per Nucleon versus Mass Number



Other radiological hazards for ions >12 amu and all conventional hazards regardless of accelerated species are addressed in the existing hazard analysis documents for the TTB and the TVDG facilities.[1, 2]

[1] Safety Analysis Report for the HITL-to-Booster (HTB) Heavy Ion Beamline, Brookhaven National Laboratory, Upton, New York 11973, October 1991. Please note that HITL-to-Booster (HTB) was renamed Tandem-to-Booster (TTB).

[2] Safety Assessment Document for the Tandem Van De Graaff Facility, Brookhaven National Laboratory, Upton, New York 11973, October 1995.

The facility characteristics that are radiation-related and the methods used in operating the TVDG and TTB and the associated equipment used to protect against the radiological hazard are documented in Section 2 of this USI. Section 3 documents the analysis, including the methodology, used for identification and mitigation of the potential radiological hazards. Section 4 documents the decommissioning plan. Detailed limits prescribed in the Accelerator Safety Envelope are documented in a separate agreement with the Department of Energy, which is attached to this USI as Appendix 4.

It is noted that this USI also updates administrative information found in the Safety Analysis Report for the Heavy-Ion-Transfer-Line to Booster (HTB), and administrative information found in the Safety Assessment Document for the TVDG. Those analyses were prepared before the transfer of the TVDG and TTB to the Collider-Accelerator Department. Please note that the HTB was renamed TTB.

1.2. Justification for Running Deuteron Beams from the Tandem to RHIC

Collisions of protons with heavy ions have long been a staple of the planned operations of RHIC. Both p-Au and p-p collisions provide comparison data sets without which one would not be able to make definitive statements about the observation and study of quark gluon plasma in Au-Au collisions. In addition, p-Au collisions, like p-p collisions, bring additional physics topics into the program.

During the first RHIC run, hints of "jet quenching" were seen in the suppression of the production of high-momentum hadrons. PHENIX and STAR reported these findings in the literature. A large quark energy loss of this type is a long-predicted quark-gluon plasma signature that has not ever been observed before.

Interpretation of the measured spectra as a new phenomenon, such as quark energy loss or jet quenching, associated with the hot and dense state produced in RHIC collisions requires the above-mentioned comparison data sets. In particular, to see whether the observed suppression is instead the result of gluon shadowing in nuclei, one must measure p-Au collisions at the same center of mass energy per nucleon as the Au-Au data sample.

The observation of this intriguing result so early in the RHIC program raises the priority of obtaining the comparison data sets. The FY01-02 running period may provide a reasonable p-p comparison sample and one should see whether a comparable p-Au sample could also be obtained.

The quickest way to p-Au collisions is to exploit the possibility of putting a deuterium beam from the Tandem into RHIC. The loosely bound deuteron will provide the same physics in collision with gold, and the better match in magnetic rigidity of deuterons with heavy ions means that head-on collisions can be obtained without moving the 12 DX magnets in RHIC. Starting with the Tandem, RHIC can be provided bunches of 10^{11} deuterons, which means that the d-Au luminosity per nucleon pair is the same as in p-p. A data taking run comparable in length to the p-p run, about 5 weeks, should provide measurements of particle yields out to a momentum of about 10 GeV/c.

1.3. Basic Safety and Environmental Protections Associated with Low-Mass Ions in TTB

The TTB and TVDG are accelerator facilities classified as low-hazard, and are subject to the requirements of the DOE Accelerator Safety Order, DOE O 420.2a or its successors. These requirements are promulgated in BNL's 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 TTB and TVDG whereby:

- They are dependant upon external energy sources; that is, electric power, that can be easily terminated.
- The primary hazard is prompt ionizing radiation that is limited to regions where the beam is maintained and is in existence only when a beam is present.

The Collider-Accelerator Department has embraced DOE's Integrated Safety Management System as a basic protection for workers and experimenters. Two Laboratory Standards promulgate the requirements of Integrated Safety Management: BNL ESH Standard 1.3.6, Work Planning and Control for Operations, and BNL ESH Standard 1.3.5, Planning and Control of Experiments.

In order to guide operations and maintenance of the accelerators, beam lines and associated systems at the Department level, BNL ESH Standard 1.3.6 is used to:

- Define the scope of work in a Work Permit or establish the applicability.
- Identify the hazards via the Work Permit process and perform a pre-job walk down.
- Use the Work Permit process to establish hazard controls and required training.
- Provide the pre-job briefing and perform the work according to plan/permit.
- Obtain feedback via the Work Permit process to identify ways to improve next time.

Experiments involving low-mass ion beams will take place in the TVDG target rooms or at RHIC and not directly in the TTB. BNL ESH Standard 1.3.5 is used by the Collider-Accelerator staff to guide experiments in order to:

- Determine the concept and scope of the experiment; assess for special requirements, review hazards and safety concerns.
- Develop an experimental plan and identify controls.
- Set up an experiment and obtain Experimental Safety Review Committee concurrence.
- Approve start-up and perform the experiment according to plan.
- Determine ways to improve next time.

Workers at the TTB or TVDG may be working in or near radiological areas. The rules in 10CFR835 establish radiation protection standards, limits and program requirements for protecting individuals from ionizing radiation resulting from the conduct of DOE activities. These requirements are promulgated in BNL's RadCon Manual. Basic radiation protection systems and programs include:

- Access Control System.
- Fixed-location and interlocking area-radiation monitors.
- Shielding, posting and fencing.
- Training and qualifications for radiation workers and visitors.
- Personnel dosimeters.
- Radiation Work Permits.
- ALARA reviews of jobs and experiments when needed.
- Radiation surveys using portable radiation monitors.
- Control of radioactive materials and sources.

The limit on the beam extracted from the TVDG or the limit on low-mass ion beam injected into the TTB is such that exposure to individuals in uncontrolled areas is likely to be less than 25 mrem in one year. For example, in the case of deuteron losses in TTB and outside 3 feet of earth shielding over the tunnel, which is an uncontrolled area, less than 25 mrem in one year is maintained with an energy limit of 12 MeV for deuterons with a pulsed-beam average-current less than 100 nA. It is noted that beam limits for specific low-mass ions are to be proscribed in terms of beam energy and intensity associated with the specific ion, in writing, by the C-A Department Radiation Safety Committee before operations.

Basic fire protection and other non-radiological issues are covered in the existing SADs for TTB and TVDG.

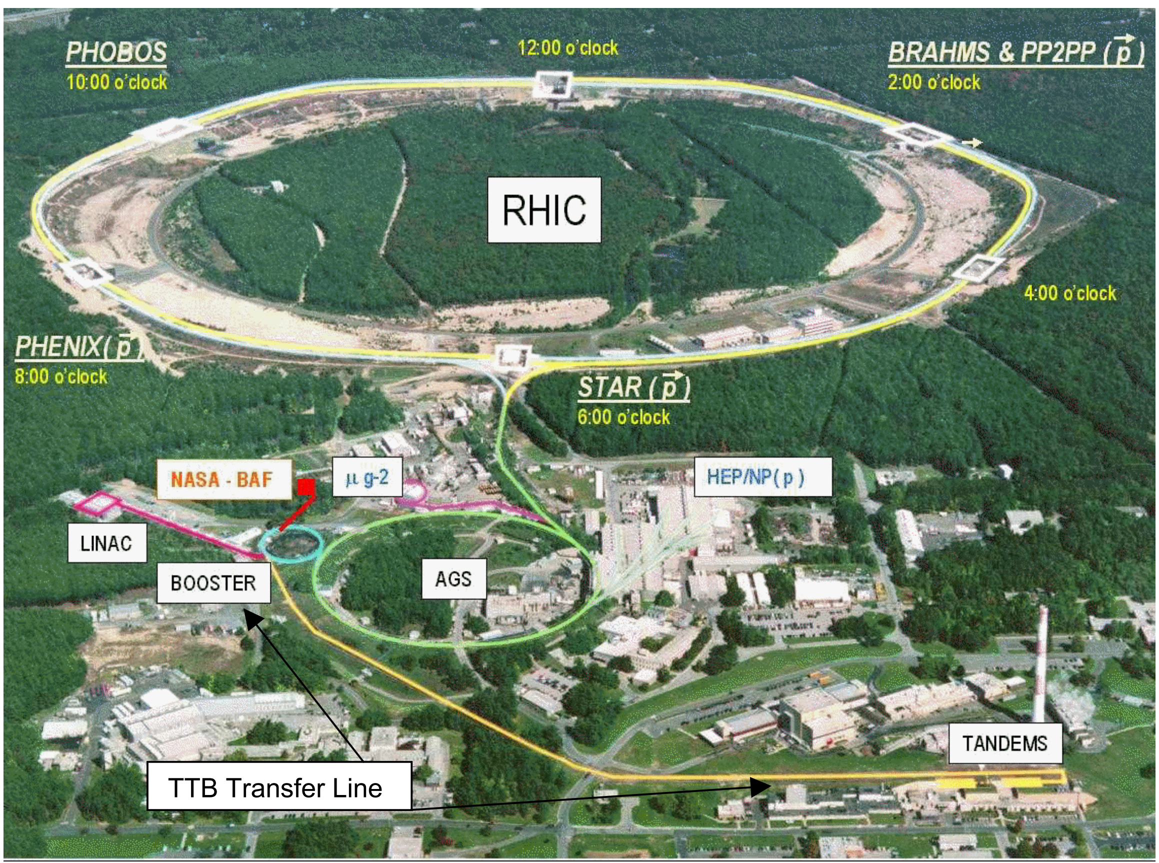
The environmental policy as set forth by Brookhaven National Laboratory in the Environmental Stewardship Policy is the foundation on which the C-A Department manages significant environmental aspects and impacts at the TVDG and TTB. The formal management program is called the Environmental Management System, which is a BNL management program that is registered to the ISO 14001:1996 Standard.

2. Site, Facility and Operations Description Associated with Deuteron Hazards

2.1. Characterization of the TTB and TVDG Site

The site geography is such that BNL is located near the center of Suffolk County, Long Island, about 60 miles east of New York City. Most of the principal facilities are located near the center of the BNL's 5,265-acre site. The developed area is approximately 1,650 acres, consisting of about 500 acres originally developed by the Army, as part of Camp Upton. The developed area is still used for offices and other operational buildings; 200 acres occupied by large, specialized research facilities; 550 acres occupied by outlying facilities, such as the Sewage Treatment Plant, research agricultural fields, housing, and fire breaks; and 400 acres of roads, parking lots, and connecting areas. The balance of the site, approximately 3,600 acres, is largely wooded and it represents native pine barren ecology. See Figure 2.1.a.

Figure 2.1.a Site Overview



The predominant groundwater flow direction in the TVDG and TTB area is to the south-southeast. The closest BNL potable water supply is supply-well 10 located approximately 2,100 feet to the east of the TTB. Results from supply-well capture zone modeling indicates that under sustained pumping conditions, approximately 8 to 10 years would be required for groundwater to travel from the TTB to supply-well 10. Based on deuteron beam energy and beam intensity, calculations show anticipated radioactivity from potentially activated soil shielding anywhere along the TTB line will not cause levels above 5% of the Drinking Water Standard (DWS); see Appendix 2. If this radioactivity in soil were to join groundwater and move to supply-well 10, then diffusion and decay would reduce levels below the DWS another factor of 250.

Based on calculations, direct radiation through shielding from TTB operations with deuterons or other low-mass ions will not affect occupants located at Buildings 901, 906 or 701, which are the closest occupied non-C-A facilities.

2.2. Design Criteria of the TVDG and TTB Access Control System

The maximum operating parameters for all ions generated at TVDG and entering TTB are to be based on radiological limits. The constraints on the maximum kinetic energy and ion current extracted from the TVDG or injected into the TTB shall be such that exposure to individuals in uncontrolled areas is likely to be less than 25 mrem in 1 year. For example, in the case of deuterons and 3 feet of earth shielding over the TTB tunnel, an uncontrolled area is maintained for 12 MeV deuterons with a pulsed average-current less than 100 nA. Fault studies show this is less than 0.1 mrem in one hour. If an 8-week deuteron-running period is conservatively assumed for shielding calculations, and occupancy outside the earth shield is assumed $1/16^{th}$ of this period or 84 hours,[3] then the potential exposure is less than 10 mrem in a year.

Normal deuteron injection into TTB is planned to be pulsed and the dc average deuteron-current is:

$$(100{,}000nA)\left(\frac{0.0005s}{pulse}\right)\left(\frac{4\,pulses}{3s}\right) = 67nA$$

Interlocks are used to limit the deuteron energy to 12 MeV or less. This is accomplished by limiting the magnetic field in the bypass dipoles. These bypass dipoles limit the energy of deuterons from the MP6 Tandem into the TTB line. Units to limit electric current to these bypass magnets are installed. An equivalent method to limit electric current to magnets in the transport line will be used if deuteron beam has to be delivered via the MP7 Tandem.

The maximum sustainable dc-average deuteron-fault-current is 10,000 nA. Experience shows that this maximum current is limited by machine design. Neither MP6 nor MP7 have been observed to sustain 100,000 nA for more than a few seconds.

In order to limit beam intensity, a harp or equivalent device is used to continuously intercept a fraction of the beam. At 6 MeV per amu, average deuteron currents above about 200 nA are prevented by redundant radiation monitors (Chipmunks) placed at the harp, which is a fixed fractional beam-loss point. The harp transparency is 85%, which results in 15 mrem/h at 1-meter

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[3] NCRP Report 49, Structural Shielding Design and Evaluation for Medical Use of X Rays and Gamma Rays of Energies Up To 10 MeV, see Table 4, Appendix C, National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Washington, DC 20014, September 1976.

lateral to a 100 nA deuteron beam. Chipmunk radiation monitors will be nominally set to trip the deuteron beam off if levels exceed about 25 mrem/h at this fixed fractional beam-loss point. The loss of a harp wire will lower the Chipmunk response, which in turn will trigger operator action such as a visual inspection of the harp.

The existing hard-wired, non-computer, relay-based Access Control System is used to permit entrance to beam areas only when it is safe to do so. An efficient and cost-effective approach to the access controls implemented in the TVDG and TTB for deuteron operations was to augment the present relay-based access controls system with a dual set of door interlocks in the TVDG and a beam intensity monitor that operates with two interlocking and alarming Chipmunk radiation monitors. Requirements for this system follow established Collider-Accelerator Department guidelines for limiting and controlling personnel access to beam enclosures, and for controlling possible prompt radiation concerns in adjacent areas.[4]

2.2.1. Description of the Access Control System

The layout of the access control system in Building 901 is shown in Figure 2.2.1.a. The radiation zones of the accelerator are separated into the low energy and high energy ends of both MP-6 and MP-7. Each end includes the zones on both the main floor and in the pit or basement. The upstairs and corresponding downstairs zones of each end are protected by a common radiation monitor. When a zone has been properly swept and the appropriate pushbuttons pressed during the inspection tour, a blinking red light at each pushbutton station will stop blinking. A purple light is illuminated on the main Radiation Display Panel. Rotating beacon-type lights are used to alert personnel in the zone and indicate that the radiation level in that zone is either at the yellow or red level. The zone is then set and may only be entered with caution if either there is no light or the yellow light is on. If the red light is on with the gates reset, then the area is an exclusion area and entering that area will break a gate switch and insert the beam stops.

The layout of the access controls in the TTB is shown in Figure 2.2.1.b. The TTB access controls include: 1) 34 reset stations, 2) 13 crash buttons that are spaced every 200 feet, 3) 12 light beam locations, and 4) 6 emergency exit locations. The TTB is an exclusion area during periods of beam transport, and is searched and secured by the appropriate TVDG operations personnel. The sweep procedure is similar to the one used in the TVDG facility. The TTB is comprised of 13 contiguous zones, each having nominally three inspection stations associated with it. Most zones have two or three entrance/exit points; egress from any zone is successfully made by activating the station at the exit point. The identification of areas within zones is posted on the cable trays. There is a nominal time restriction of two minutes for the setting of any zone to prevent leaving a "hanging," or partially set zone. Activation of any internal inspection station resets the time delay to the two-minute mark.

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[4] Guidelines for Radiological Controlled Area Classification and Radiation Access-Control System Application, C-A OPM 9.1.11, http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-11.PDF

Figure 2.2.1.a Access Control System Component Location in Building 901 that Houses the Tandems

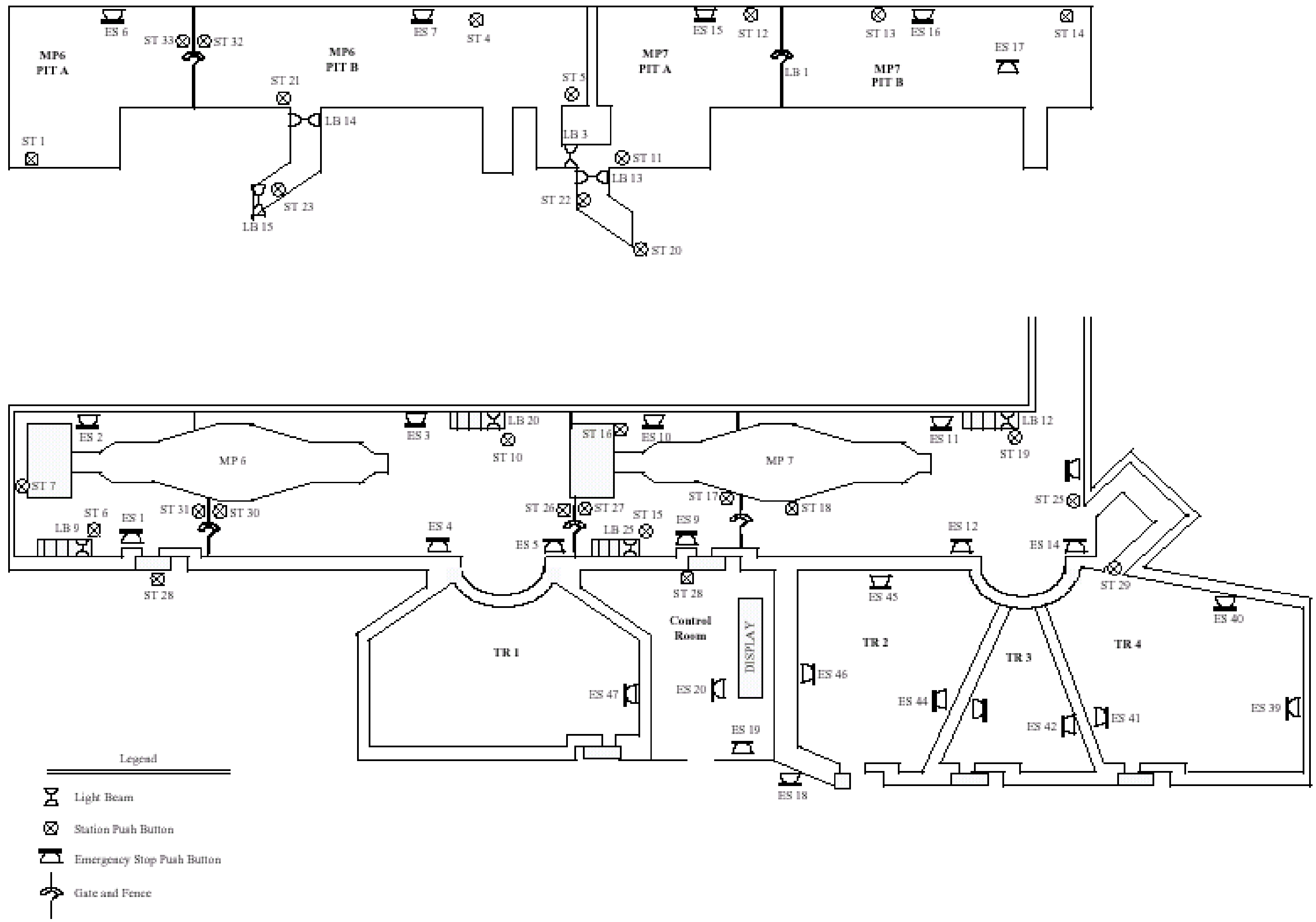
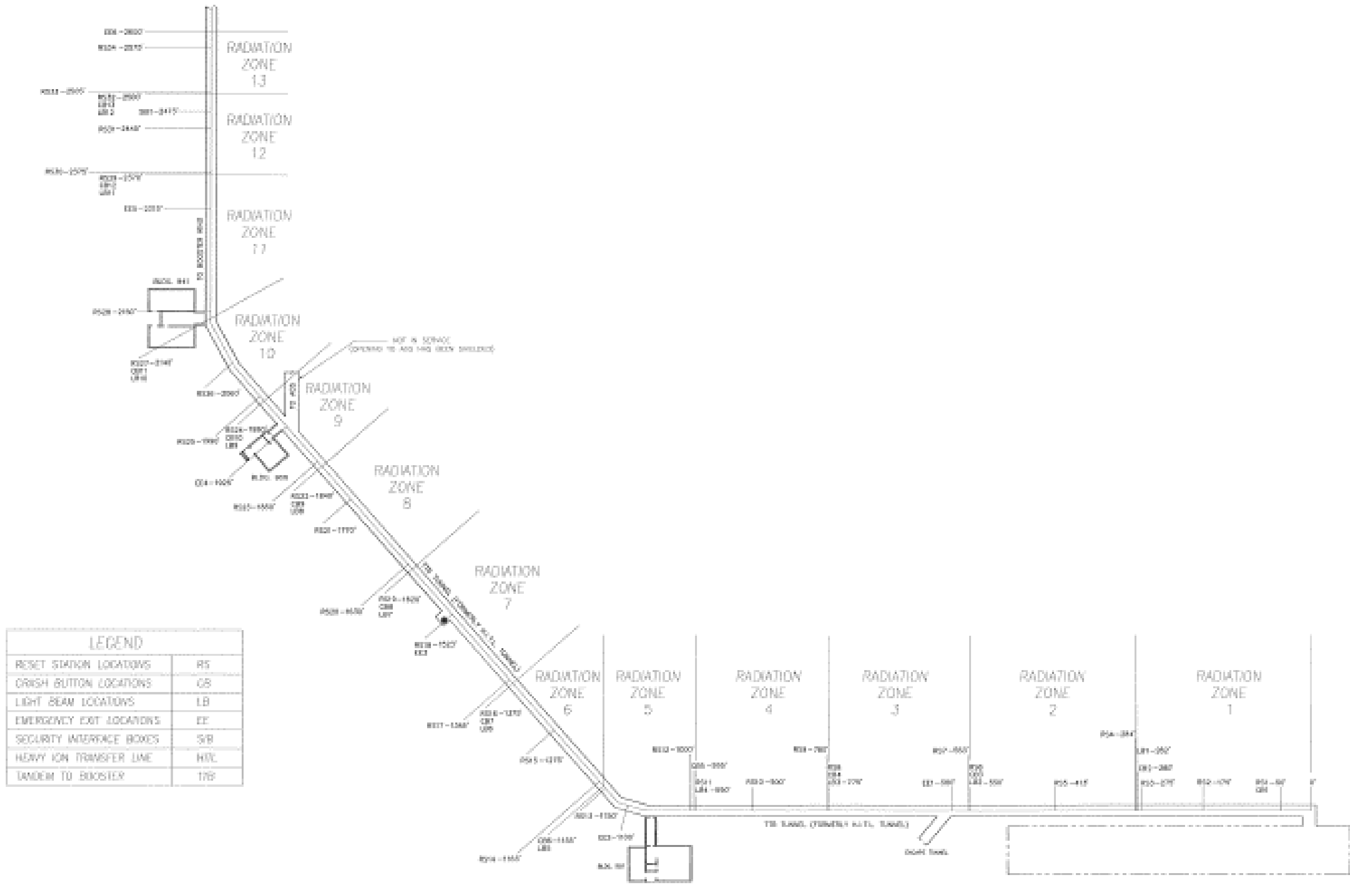


Figure 2.2.1.b TTB Access Control System Layout



Critical devices are beam-line elements that when placed in a safe state will eliminate the radiation hazard from the beam to safely permit access. As with other aspects of the access controls system, Collider-Accelerator Department requires two completely separate critical devices to be in force before allowing access to any area that can produce greater than 50 rem in one hour from beam (see Table 3.3.3 for potential radiation levels inside the enclosures). Each of these separate critical devices must mitigate the radiation hazard by itself. In the case of operations with 6.0 MeV/nucleon deuterons, the level of 50 rem in one hour from beam is achievable. Thus, two critical devices located in the TVDG are used to prevent beam acceleration and allow access.

As opposed to implementing the critical devices through the actions of an Operator before an authorized entry, unauthorized access through gates or hitting a crash button causes the critical devices to be implemented directly, and this immediately prevents TVDG beam.

For C-AD Class I, II, III or IV areas (see C-AD OPM-ATT 9.1.11.a), the Operators must ensure that the beam line enclosure is cleared of personnel before permitting beam into any beam line. This is accomplished by a search of the area followed by an area reset.

All operators are trained by personal instruction on the part of the supervisory staff by walking through the inspection and sweep procedure for each of the radiation zones. Each operator is also referred to drawings for detailed reference to all of the various light beam areas, station pushbuttons, emergency stop pushbuttons and door and gate switches. Complete drawings of the entire system are on file along with the rest of the control drawings for the accelerator facility. All areas or zones may be set to safely allow radiation in those areas. The special passageway entrances into the accelerator areas are set first since access to the accelerator is through these passageways. Use of these passageways is rare. They are normally used only in emergency conditions.

Other access-control-system devices include active radiation area monitors that reduce or eliminate unwarranted prompt radiation levels in occupied areas due to fault conditions. Active monitoring may be provided in the TTB to monitor deuteron beam losses. The radiation area monitors used for this task are interlocking ionization chambers called “Chipmunks.” These devices are suitable for pulsed neutron and gamma radiations, and they readout in dose equivalent, a physical unit that is based on assuming an appropriate quality factor for the neutron energy spectrum. The possible need for Chipmunks and the appropriate locations are decided by the Radiation Safety Committee after results of fault studies are reviewed.

As mentioned in Section 2.2, Chipmunk radiation monitors interlock the TVDG injected beam should significant TTB beam above 100 nA be detected. The Radiation Safety Committee may change the interlock level to higher levels depending on need and ALARA considerations. It is noted that TVDG operator response to alarms and interlocks is governed by formal reporting requirements set down in the Collider-Accelerator Operations Procedure Manual.

2.3. Design Features that Minimize Hazards and Prevent Pollution

The as-built characteristics that minimize the presence of hazardous environments and ensure chemical and radiation exposures are kept as low as reasonably achievable during operation, maintenance and facility modification are as follows:

Radiation Safety

- Fail-safe dual interlocks are used on gate entrances in the TVDG.
- Fail-safe interlocks are used on gate entrances in the TTB.
- Crash buttons are mounted inside the TVDG, TTB, control room, hall and target rooms.
- Interlocking area radiation monitors with pre-set trip levels are located at a fixed beam loss point in the TVDG.
- Full enclosures with interlocked gates are darkened, which is a visual warning, before re-enabling the beam line to receive beam.
- The TTB is fully enclosed to prevent access during operations.
- Fencing is used to limit access to radiological areas.
- Shielding is thick enough to prevent exposure to primary beam.

Access Control

- Either the beam is disabled or the related access control area in TTB is secured.
- Only wires, switches, relays, programmable logic controllers and Collider-Accelerator Department Radiation Safety Committee approved active fail-safe devices are used in the critical circuits of the system.
- Where relays are used, the de-energized state of a relay is the fail-safe state; that is, the system is fail-safe.
- Redundant critical devices are used to disable beams capable of causing greater than 50 rem in one hour at one foot.
- Sweeps and reset stations are used to secure the radiological areas.

ALARA

- Multi-leg penetrations and labyrinths or long tunnels are used to minimize routine radiation levels.

Liquid Effluents

- A sump and sump alarm are located in the TTB and TVDG basement to capture cooling water should it leak. The TTB alarm is local and the TVDG alarm is monitored by Plant Engineering Division.
- All drain piping in the TTB and TVDG is connected to the BNL Sanitary Sewage System.
- All cooling water systems have water make-up alarms.
- There are no outdoor tritiated water piping or cooling systems.
- The domestic water supply is equipped with back-flow preventers to isolate the TTB and TVDG domestic water supply systems.
- The feeds on the cooling systems have back-flow preventers.

It is noted that the liquid effluent protections are primarily for prevention of cooling water with high concentrations of metals from entering the sanitary lines. Cooling water in the TVDG and TTB magnets and other beam-line components may contain dissolved metals from corrosion of beam-line components. The metals are typically copper and iron. There is no concern for tritium in cooling water since there is no production cross-section for tritium from neutron interactions on oxygen or hydrogen in water. However, trace amounts of activated corrosion products may be present. All water-cooling systems at Collider-Accelerator facilities are sampled twice per year in order to quantify radioactive materials and metals concentrations.

2.4. Collider-Accelerator Department's Organization

The Collider-Accelerator 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 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 Collider-Accelerator Department is under a formal Conduct of Operations Agreement with the Department of Energy.[5] The documentation used to comply with this agreement is the Collider-Accelerator Department Operations Procedure Manual, C-A OPM,[6] which specifies key procedures, chain of command, authorized personnel and other operational aspects. 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.

The Collider-Accelerator Department organization[7] is comprised of four Divisions, the Accelerator Division, the Experimental Support and Facilities (ES&F) Division, the Controls Division and the Environmental, Safety, Health and Quality (ESHQ) Division. It is the responsibility of the Accelerator Division to bring the Siemens motor generator or Westinghouse motor generator, TVDG, Linac, Booster, AGS and RHIC on line and to integrate the operation of these machines into that of the complete facility. The beams from the operation of these machines must be transported by the Accelerator Division through transfer lines; for example, TTB and AtR, and to experimental areas; for example, TVDG Target Rooms, Booster Applications Facility Target Room, Building 912 and Building 919 Target Caves and at the RHIC intersecting regions. It is the responsibility of the ES&F Division to plan, design, build and maintain the primary and secondary experimental beam lines and provide technical support for instrumentation for experiments or accelerators. It is the responsibility of the Controls Division to provide software and hardware controls and support for the accelerators. It is the responsibility of the ESHQ Division to provide environmental protection, safety and health related services to the staff, experimenters and visitors. The ESHQ Division provides technical work products, training services, referrals to outside professionals, documentation services,

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[5] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm Conduct of Operations Agreement
[6] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm Operations Procedure Manual
[7] http://www.rhichome.bnl.gov/AGS/Accel/SND/OrgChart/OrgChart.pdf C-A Organization Chart

conventional and radiological safety services, environmental management and internal assessment resources to help resolve ESHQ problems and meet requirements.

2.4.1. Operations Organization Introduction

The RHIC, AGS, Booster and Linac operate through the Collider-Accelerator Department Main Control Room (MCR) in Building 911. The operation of the TVDG is from the Tandem Control Room in Building 901A. The operation of the TTB is possible from either of two separate locations, the Tandem Control Room in 901A or the MCR. Beam tuning and equipment control up to the two redundant TTB beam stops located near the Linac tunnel is normally provided by the Tandem Control Room. Control of these beam stops and, in most cases, the tuning of the beam beyond this point to the Booster is accomplished by the MCR operators. Status information and alarms are displayed in both control rooms. Communication links include shared intercom channels, telephones and PA systems.

The Collider-Accelerator Department organization for operations is pictured in Figure 2.4.1. Responsibility for the safe and reliable operation of the Collider-Accelerator Department complex resides with the on-duty Operations Coordinator in MCR. The Operations Coordinator is the shift supervisor for the operating personnel and the focus for all operations related questions. The Collider-Accelerator Department complex is made up of a number of facilities that may include the TVDG, Linac, Booster, AGS, the Main Magnet Power Supply, rf acceleration system, injection equipment, extraction equipment, beam lines and the RHIC. Personnel that are responsible for the day-to-day operations of these facilities are members of the Accelerator Division, the ES&F Division, the ESHQ Division and the Controls Division. Additional personnel who support the operations are members of BNL's Radiological Controls Division, Environmental Services Division, Waste Management Division and Plant Engineering Division.

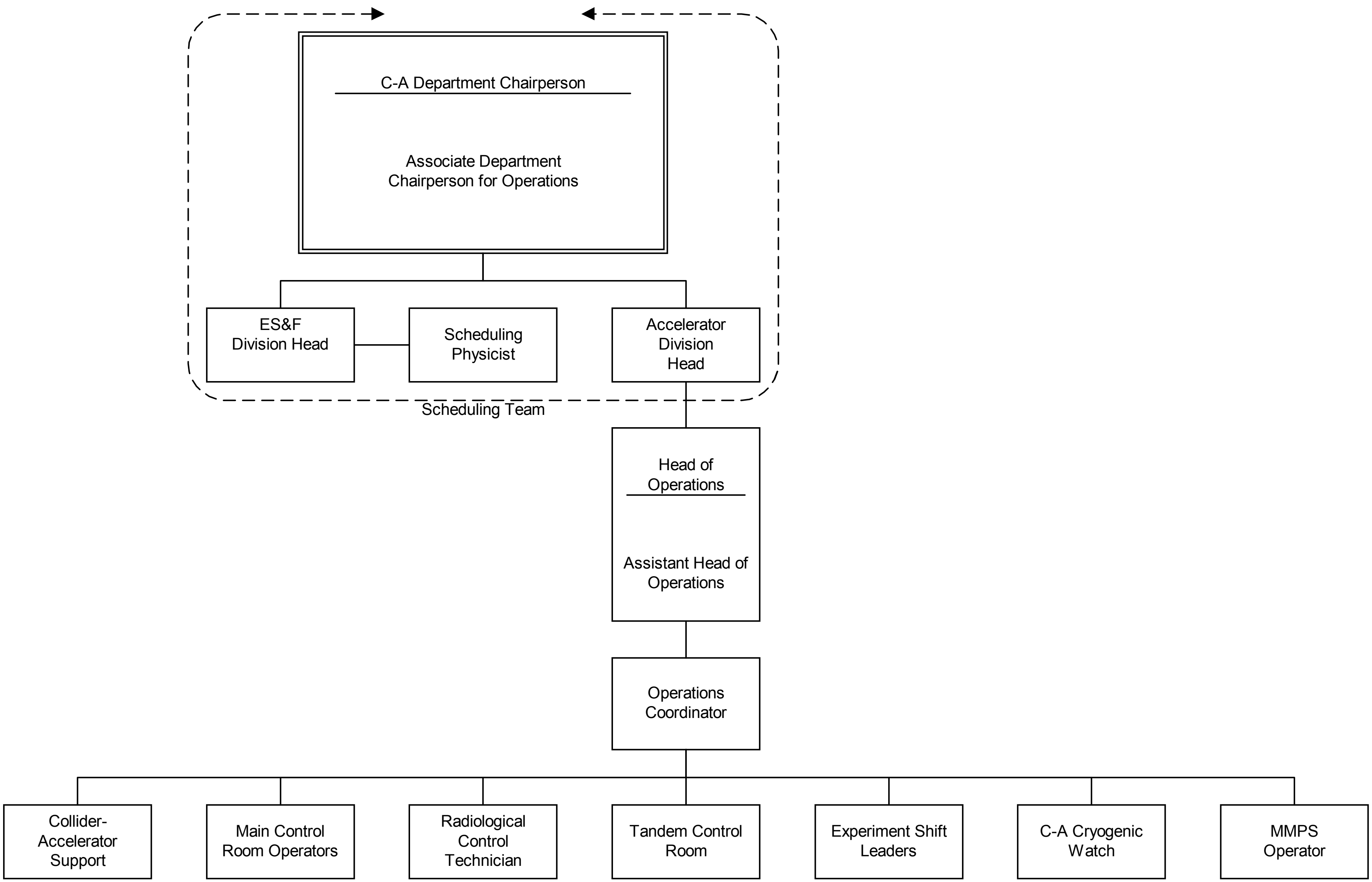
Depending on operations, personnel available to the Operations Coordinator during operations may include:

- The Main Control Room Operators.
- The Collider-Accelerator Support Group who are responsible for experimental area systems and beam line components.
- Power Room Operator who is responsible for the control of the Main Magnet Power Supply.
- Cryogenic Target Watch who are responsible for the operation of the liquid cryogenic targets, if any.
- Cryogenic Control Room Supervisor and Operators who are responsible to operate the refrigeration systems for cooling cryogenic magnets.
- Radiological Control Technician.
- Experiment Shift Leaders at the Collider.
- TVDG Control Room Operators.

Additional personnel available to the Operations Coordinator include the accelerator physicists and equipment systems specialists. Systems specialists repair equipment necessary for operations or provide trouble-shooting expertise when machine physics or equipment problems arise. Occasionally, it is necessary that parts of the accelerator complex be operated by accelerator physicists or systems specialists. The rules governing access to accelerator controls, by such individuals, are found in the C-A OPM. In order to be allowed access to accelerator controls, accelerator physicists and systems specialists must:

- Recognize the role of the on-duty Operations Coordinator as the decision-maker regarding the safe and reliable operation of Collider-Accelerator facilities.
- Follow the orders of the Operations Coordinator, or his designate, during an emergency.
- Not operate any access-control-system consoles or equipment unless authorized to do so by the C-A Access Controls Group Leader.
- Request permission to use accelerator controls and state the purpose for the use of the controls to the on-duty Operations Coordinator.

Figure 2.4.1 C-A D Operations Organization



2.4.2. Operations Authority

Safe operation and maintenance of the Collider-Accelerator Department's science and technology (S&T) machines, injection systems, and experimental areas are under the supervision of the Collider-Accelerator Department Chair, the Accelerator Division Head, the Experimental Support & Facilities (ES&F) Division Head, the on-duty Operations Coordinator, and the supervisory structure. See the Collider-Accelerator Organization Chart.[8]

Only authorized Department personnel operate the S&T machines. Direct daily supervision of shift operations is the responsibility of the on-duty Operations Coordinator. All Operators are authorized to shut down the S&T machines whenever an unsafe condition arises, or whenever they think that continued operation is not clearly safe. They are also authorized to take any other corrective safety- or environmental-protection-action as indicated in the C-A OPM. All scheduled operational-related maintenance is done with the authorization of the appropriate Work Coordinator, with the work-control authorizations prescribed in the C-A OPM and with the knowledge of the on-duty Operations Coordinator.

All operations have the appropriate authorization. Current holders of positions are denoted in the Collider-Accelerator Organization Chart. The following operations authorities are listed in the OPM:

- Department Chair Authorization
- Associate Chair Authorization
- Assistant Chair Authorization
- Division Head Authorization
- Group Leader or Supervisor Authorization
- Authorization to Operate Systems
- S&T Machine Startup or Restart Authorization
- Work Control Authorization
- Maintenance Coordinator Authorization
- Authorization to Classify, Remove or Designate Approval for Procedures
- Department Chair, Division Head, Group Leader, Committee Chair and QA Authorization of Procedures
- Committee Membership and Organization Chart Authorization
- Modification of Training Authorization
- Authorization to Approve QA Level Classifications
- Authorization to Approve Purchase Requisitions and Intra-Laboratory Requisitions for ESHQ Compliance
- Authorization to Declare Systems As "Critical"
- Authorization to Approve Working Hot Permits & Procedures
- Authorization to Approve Lock and Tag Checklists
- Authorization to Approve Experiments
- Authorization to Approve New or Modified Accelerator Systems

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[8] http://www.rhichome.bnl.gov/AGS/Accel/SND/OrgChart/OrgChart.pdf C-A Department Organization Chart

2.4.3. Administration and Organization of ESHQ

The administration of ESHQ at Collider-Accelerator Department is via a hierarchy of documents: BNL Policies, BNL Standards of Performance, R2A2s, BNL Management Systems, BNL Subject Areas, Collider-Accelerator Department Conduct of Operations Agreement, Collider-Accelerator Department Facility Use Agreements, and at the working level, department procedures (Operations Procedures Manual, OPM).

BNL ESHQ Policies are the highest-level statements of BNL organization's philosophy for conducting business in a safe and environmentally sound manner. The number of policies is small. Policies are intended to form the complete set of foundational philosophies upon which the Laboratory operates.[9]

Standards of Performance are BNL "requirements" underlying Laboratory-wide procedures. Standards of Performance are intended to set performance expectations for BNL systems, managers and staff in accomplishing BNL Policies. By definition, the term "staff" includes all BNL staff and managers. Standards of performance also apply to those guests, visitors, and users who have a guest number and have been issued a DOE photo identification badge. Standards of Performance are high-level behaviors by which BNL carries out its policies, and are used to determine whether we are conducting our business and ourselves consistently with our mission, values and aspirations.[10]

The role, responsibility, accountability and authority statements (R2A2s) establish the expectations and duties of managers and staff for carrying out the work consistent with external and internal requirements.[11]

Management Systems are designed to translate the full set of external requirements into the information staff need to perform their work. Management systems are BNL's highest-level operating and business processes.[12]

Subject Areas are prepared when the requirements, procedures and guidelines apply to a broad group of staff across BNL.[13] If information only applies to a select or small group of staff, alternate methods of communications exist, such as task- or group-specific internal operating procedures. Subject Areas provide Laboratory-wide procedures and guidelines. Subject Areas are developed to support the implementation of Standards.

In some cases, specific program description documents are used as the basis for operations by discrete groups of BNL staff that perform key activities to operate the processes and systems. In the case of the Collider-Accelerator Department, the basis for operations is defined in the Conduct of Operations Agreement with DOE.[14]

A Facility Use Agreement (FUA) with the BNL Directorate is also established for Collider-Accelerator facilities such as the TVDG and TTB. The Collider-Accelerator Department Chairman, the Assistant Laboratory Director for Facilities and Operations, and the Deputy Director of Operations are the agreement parties for the FUA. The FUA clearly documents the respective roles, responsibilities and authorities for the Collider-Accelerator Department Chair and the Assistant Laboratory Director for Facilities and Operations for all

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[9] https://sbms.bnl.gov/policies/cl00d011.htm BNL Policies
[10] https://sbms.bnl.gov/perform/gstdd011.htm BNL Standards of Performance
[11] https://sbms.bnl.gov/standard/0x/0x00t011.htm Roles, Responsibilities, Accountabilities and Authorities
[12] https://sbms.bnl.gov/mgtsys/ms00t011.htm Management System Descriptions
[13] https://sbms.bnl.gov/standard/0000t011.htm Subject Areas
[14] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm Conduct of Operations Agreement

aspects of facility operations. The DOE approved safety/authorization basis document for TTB and TVDG, which is the Accelerator Safety Envelope (ASE),[15] is a referenced attachment to the FUA. Facility Use Agreements (FUAs) point to the operating boundaries/requirements including roles and responsibilities for the TTB and TVDG facilities.[16]

Internal operating procedures include task- or group-specific procedures that are used to implement management system processes. Collider-Accelerator Department procedures typically affect only the Collider-Accelerator Department facilities, which in this specific case are the TVDG and TTB. The Collider-Accelerator ESHQ Division ensures that Operations Procedures are current. The ESHQ Division also ensures procedures are based on and not in conflict with the Laboratory-level governing documents mentioned previously.[17]

Each individual at the Collider-Accelerator Department is responsible for knowing and observing the rules. If any trained personnel observe any potential hazards, environmental problems or safety problems, then they must stop the work or activity and report it. Supervisors are responsible for all activities conducted within their facilities. Collider-Accelerator Department managers are committed to providing a safe and healthy working environment for all staff; protecting the general public and the environment from unacceptable environmental, safety and health risks; operating in a manner that protects the environment by applying pollution prevention techniques to current activities; and remediation of environmental impacts of past operations.

All Collider-Accelerator personnel are knowledgeable in applicable procedures located in the C-A OPM. The OPM is designed to be a controlled document and to conform to quality assurance requirements set down in the Collider-Accelerator Quality Assurance Procedures.[18]

The Collider-Accelerator Department ESHQ organizations are indicated in Figure 2.4.3. Several key ESHQ organizations and programs are described as follows:

The Associate Chair for ESHQ is a member of the Collider-Accelerator Department Chair's Office. The Associate Chair's functions are to implement new or revised environmental, safety, health, training and quality programs, to carry out the leadership role for ESHQ, to inform personnel on the status of ESHQ, to establish communications and to maintain existing ESHQ programs. The overall approach is to integrate ESHQ into all work via formal Collider-Accelerator programs and procedures designed to ensure BNL's management systems are executed. BNL's management systems, which are located in the Standards Based Management System,[19] are in turn designed to ensure that contractual requirements set by DOE are met.

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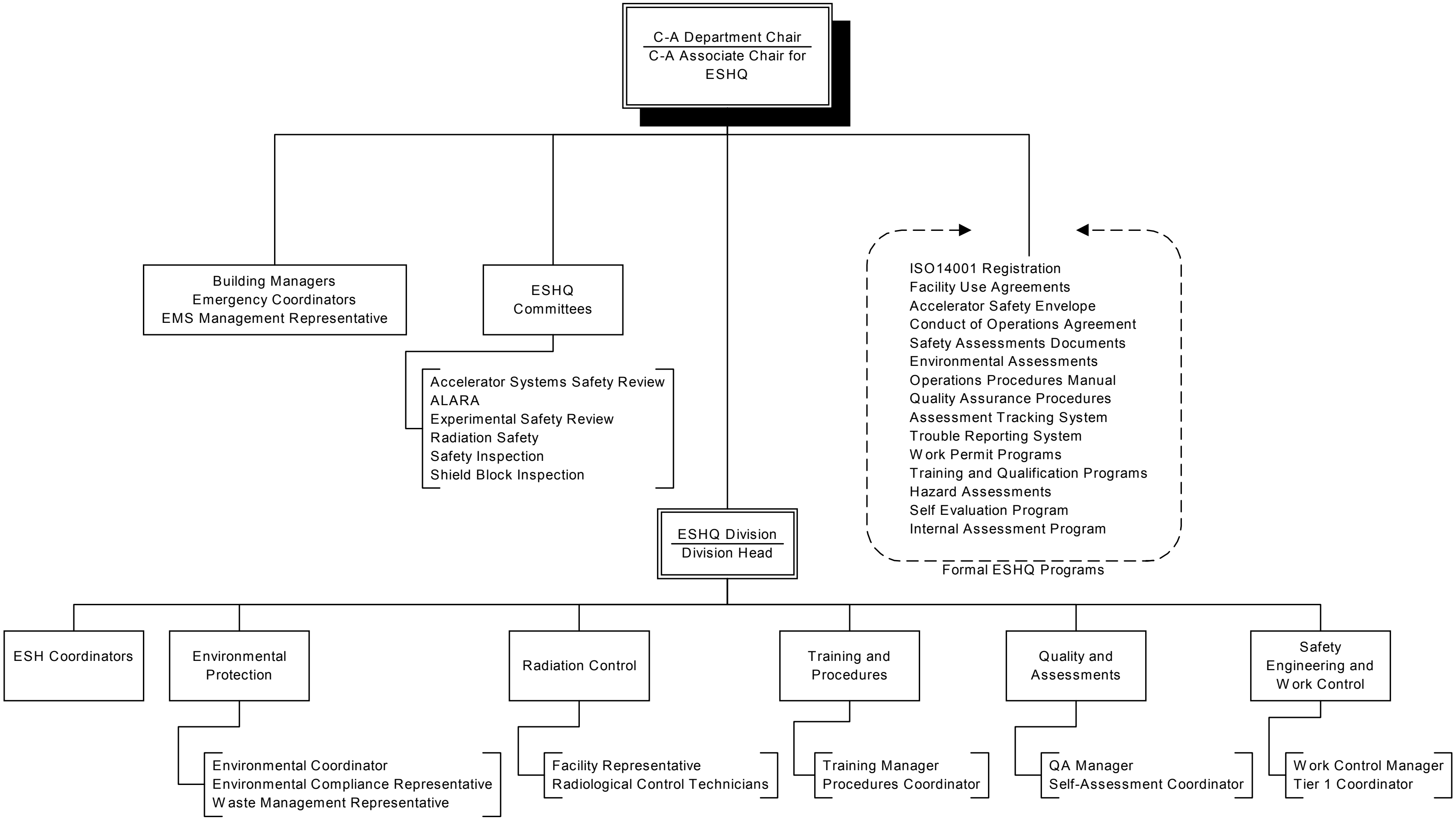
[15] http://www.rhichome.bnl.gov/AGS/Accel/SND/USI/Appendix4TTB.pdf Appendix 4, Proposed Accelerator Safety Envelope for the TTB and TVDG
[16] https://sbms.bnl.gov/private/fua/fa00t011.htm Facility Use Agreements
[17] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm C-A Department Procedures
[18] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm C-A Quality Assurance Procedures
[19] https://sbms.bnl.gov/ch00d011.htm, BNL's Standards Based Management System

Figure 2.4.3 Representative Organization and Formal Programs for ESHQ at C-AD



For DOE, "safety" encompasses environmental protection, safety and health, including pollution prevention and waste minimization. DOE has identified five Core Functions to manage "safety." They are:

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

DOE has identified seven Guiding Principles for performing the five Core Functions. The first three Principles apply to all Core Functions, the others to specific Functions given in parentheses:

- Line managers clearly responsible for ESH (all Core Functions).
- Clear ESH roles and responsibilities (all Core Functions).
- Competence commensurate with responsibilities (all Core Functions).
- Balanced priorities (define work).
- Identify ESH standards & requirements (define work, identify hazards, develop controls).
- Hazard controls tailored to work (develop controls).
- Operations authorization (perform work).

The management system that includes the five Core Functions and seven Guiding Principles has been named Integrated Safety Management (ISM) by DOE. BNL's management systems to implement ISM are located in the Standards Based Management System (SBMS). SBMS is on-line with hypertext links to all referenced documents. The SBMS satisfies the contractual requirement for ISM. SBMS includes the following principle ESH programs and management systems:

- BNL's Integrated Assessment Program.
- Laboratory level work-definition documents such as Subject Areas and BNL ESH Standards.
- Facility Use Agreements (FUA's).
- Role, Responsibility, Authority and Accountability documents (R2A2s) and performance goals.
- Brookhaven Training Management System (BTMS).

At the Department level, BNL ESH Standard 1.3.5, Planning and Control of Experiments, is used by the Collider-Accelerator staff to guide experiments in order to:

- Determine the concept and scope of the experiment; assess for special requirements, review hazards and safety concerns.
- Develop an experimental plan and identify controls.
- Set up an experiment and obtain Experimental Safety Review Committee concurrence.
- Approve start-up and perform the experiment according to plan.
- Determine ways to improve next time.

In order to guide operations and maintenance of the accelerators, beam lines and associated systems at the Department level, BNL ESH Standard 1.3.6, Work Planning and Control for Operations, is used to:

- Define the scope of work in a Work Permit or establish the applicability.
- Identify the hazards via the Work Permit process and perform a pre-job walk down.
- Use the Work Permit processes to establish hazard controls and required training.
- Provide the pre-job briefing and perform the work according to plan/permit.

- Use the Work Permit feedback process to identify ways to improve next time.

The Collider-Accelerator Department uses committees and ESH staff to define the scope of the experiment or work, identify and analyze hazards and develop hazard controls. The ALARA Committee, Experimental Safety Review Committee, Accelerator System Safety Review Committee and Radiation Safety Committee meet requirements established in BNL ESH Standards 1.3.5 and 1.3.6. These Committees are composed of members of the Collider-Accelerator Department, other BNL scientific Departments, and members of the BNL ESHQ Directorate. These Committees operate under a system of formal procedures that are listed in the C-A OPM.

Self-assessment and self-evaluation are carried out by individual Department employees and by Collider-Accelerator Department's Safety Inspection Committee, Shield Block Inspection Committee and Quality Group. Formal procedures for conducting self-assessment and self-evaluations are listed in the C-A OPM. Formal tracking of commitments and action items is via the Assessment Tracking System (ATS).[20]

2.5. Engineered and Administrative Controls Summary

The engineered control for routine operation and emergency conditions is the Access Control System (ACS). The purpose of this safety significant system is to prevent inadvertent exposure to particle beams and to the secondary radiations that follow particle beam interactions. The Collider-Accelerator Department Radiation Safety Committee (RSC) has defined the classification of the TTB and TVDG Access Control System and its application.

The RSC delineated the access, the enclosures and the minimum access-control requirements for each Class of radiation area at these facilities, and accounted for the potential levels of radiation during normal operations and the potential radiation levels during fault or abnormal conditions. Since anticipated routine beam losses and tuning efforts will lead to periodic levels of about 150 mrem/h in the TVDG accelerator room and the TTB tunnel, these areas were classified as Class IV (>100 mrem/h and <5000 mrem/h) as per RSC requirements in C-A Department OPM 9.1.11. Because of the potential for beam losses that may lead to >50 rem/h and <500 rad/h (see Section 3.3.3), the accelerator room would also be categorized as Class II in a fault condition using deuteron beams normally meant for the TTB. However, in order to enable the broadest choice of beams in the accelerator room, as opposed to the TTB, fault levels in the accelerator room were categorized as Class I (>500 rad/h). As per C-A OPM 9.1.11, a Class IV area that can fault to Class I, which in this case is the accelerator room, the ACS must meet the following requirements:

- Walls, fences and locked gates
- An impregnable enclosure with hard-wired, dual fail-safe interlocked gates
- Devices used for beam control must be hard-wired, dual and failsafe
- An active alarm system to warn of excessive radiation levels must be in place

In addition, controlling access and beam enablement are basic requirements for a C-A Department Class IV areas, which in this case is the TTB. These Department requirements have been met for the TVDG accelerator room and the TTB.

Wiring diagrams and functional tests are approved by the RSC. All ACS wiring and testing is performed and documented by qualified technicians and engineers in the Collider-

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

Accelerator Access Controls Group. Changes to the system are controlled according to requirements in the BNL SBMS, Collider-Accelerator Department Quality Assurance Procedures and the C-A OPM. The ACS is a QA1 system, and all drawings and components are configuration controlled.

The requirements for calibration, testing, maintenance, accuracy or inspections for the ACS necessary to ensure the operational integrity of the radiological aspects of the TVDG/TTB Accelerator Safety Envelope are:

- The ACS is functionally tested in accordance with requirements in the BNL Radiological Control Manual.
- Area radiation monitors undergo annual testing not to exceed 15 months.
- Radiological barriers undergo annual visual inspection not to exceed 15 months.

The administrative controls for routine operation and emergency conditions are:

- Emergency Procedures - Emergency response is governed by procedures in the C-A OPM. The emergency plan covers possible hazards, emergency signals and expected responses. Each building at the Collider-Accelerator Department complex has signs posted indicating the emergency assembly areas, and the name and number of the Local Emergency Coordinator. The Local Emergency Coordinator is familiar with the hazards in the building, the utility locations and shut-offs, and any spill response supplies available. The Local Emergency Coordinator assists the Fire Rescue Group Incident Commander in responding to any incidents at the facility.
- Radiation Protection – The radiation protection program at Collider-Accelerator Department is in accord with the BNL Radiological Control Manual[21], which in turn complies with Title 10 Code of Federal Regulations Part 835, Occupational Radiation Protection. In addition to Radiological Control Division procedures,[22] The C-A OPM includes task- or committee-specific radiological procedures such as C-A OPM 9.1.11 that are used to implement local requirements and the requirements in the BNL Radiological Control Manual.

2.6. Critical Operations Procedures

Specific operations procedures that prevent or mitigate radiological accidents are related to resetting the ACS to enable beam. These procedures involve clearing personnel from beam lines (sweeping) before enabling the beam line for potential operations. These procedures are found in the C-A OPM. The basic principles behind the authorization and use of these procedures are:

- Wording must be consistent throughout the entire set of sweep procedures for the Collider-Accelerator Department; that is, specific terms must mean the same regardless of the location of the area being cleared of personnel.
- Before resetting for beam, it must be clear to the operator which sweep procedure from the set of sweep procedures applies under every access condition encountered in the field. If not, then the area is not reset for beam.
- New or modified sweep procedures must receive an independent review by the maintenance staff or their representative; these are staff normally cleared (swept) from the area.

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[21] https://sbms.bnl.gov/program/pd01/pd01t011.htm BNL Radiological Control Manual.
[22] http://intranet.bnl.gov/rcd/ BNL Radiological Control Division.

Less critical procedures for operation of the Tandem with low-mass ions in the TTB account for the administrative limit on the terminal voltage to 6 MV or less, and the limit on intensity to 200 nA dc average current or less. Normally, low-mass ions will be from MP6 only, unless RSC approval to run from MP7 is obtained. Other administrative issues to be covered by procedures or the RSC check off list include:

- Redundant interlock string is to be switched in.
- Bypass line dipole fields are to be limited.
- Harp or equivalent beam intensity monitor is to be locked in the inserted position, and Chipmunk interlocks switched in.
- Target room beam plugs must be put in or target room secured.

Operation of the Tandem with low-mass ions for TVDG target rooms requires a procedure to switch in redundant interlocks, including the target room door. A procedure for entry into an accelerator tank after having run with deuterons will include a check for contamination by the RCTs. Finally, an ALARA procedure to minimize the use of Faraday cups in TTB when running deuterons is in place since Faraday cups create a point source albeit briefly.

2.7. Shielding Review by the Radiation Safety Committee

The liaison physicist presented the relevant shielding designs to the Collider-Accelerator Radiation Safety Committee, who reviewed the shielding against established criteria. Specifically, the berm thickness over the TTB tunnel is to be a minimum thickness of 3 ft before running with deuterons or other low-mass ions. Specific calculations of dose equivalent outside the shielding are found in Appendix 2. Specific estimates of the induced activity and dose rates outside the shield are provided. The Radiation Safety Committee concluded that the shield:

- Limits the annual site-boundary dose equivalent to less than 5 mrem.
- Limits the annual on-site dose equivalent in non-Collider-Accelerator facilities to less than 25 mrem per person.
- Limits the maximum accumulated dose equivalent to any area where access is not controlled to less than 20 mrem during a fault condition.
- Makes the dose equivalent rate as low as reasonably achievable (ALARA) and in no case is it greater than 0.5 mrem in 1 hour or 20 mrem in 1 week for continuously occupied locations.
- Makes the dose equivalent rates where occupancy is not continuous ALARA and in no case allows greater than 1 rem in 1 year for whole body radiation, or 3 rem in 1 year for the lens of the eye, or 10 rem in 1 year for any organ or tissue.

During the review, the Radiation Safety Committee examined the layout of the beam transport system. Possible radiation sources during fault conditions were examined. These possible sources included apertures, collimators, instrumentation, valves, Faraday cups, magnets and beam scraping in the beam transport pipe. Sources caused by improperly adjusted beam elements were also considered. Based on shielding and the results of fault studies with deuterons (see Appendix 5), the Committee then set the normal operating parameters for the TTB into the Committee records. For example, the Radiation Safety Committee approved primary beam energy and deuteron intensity for the TTB. On this basis, the Chair of the Collider-Accelerator Department's Radiation Safety Committee and the Associate Chair for ESHQ approved the shielding design and the shielding prints. The shielding prints were placed in configuration control, assigned an identifying number and made a permanent record of the shielding for the TTB.

2.8. Other Radiation Safety Committee Actions

The Radiation Safety Committee reviewed and approved the ACS for the TVDG and the TTB for low-mass ion beams. They approved the critical devices and reach-backs, and they established the conditions that the ACS must monitor; for example, the electric current on beam elements such as bypass magnets near MP6. They established the alarm level and interlock level for Chipmunk radiation monitors that intercept radiation from the fixed harp location that limits beam current. It is noted that the Radiation Safety Committee will establish the equivalence of other beam current monitors if found to be more suitable than a harp. The Radiation Safety Committee also reviewed and approved the required fault study plans. Finally, radiation surveys and fault studies were conducted at TTB and TVDG under the auspices of the Radiation Safety Committee to verify the adequacy of the shielding and the radiological area classification.

Environmental issues were also considered by the Radiation Safety Committee including soil activation, air activation, ground water activation and erosion of the soil-shield.

3. Technical Analysis of Radiological Hazards

3.1. Introduction

The TVDG/TTB design is similar to successful designs employed at other BNL accelerators and experiments, and therefore, has the same favorable safety characteristics. In addition, these facilities have performed safe operations since the TVDG was commissioned in 1970 and the TTB in 1991. Hazard analysis is the standard method for applying the DOE graded approach for minimizing risk. It is well suited to identifying and understanding risk because it requires consideration of both the likelihood and the potential consequences of hazards. The product of likelihood and consequence constitutes the risk. When using risk as the measure of acceptance, the allowable consequences for lower likelihood events are higher than for the higher likelihood events. In the hazard analyses presented here, the approach has been to evaluate the risk introduced by deuteron running in the TTB and to identify preventive and mitigating features that ensure that risk is acceptably low. The reader is referred to the existing hazard analysis documents for the TTB and the TVDG facilities for all other radiological and conventional hazard analyses.[23, 24]

3.2. Risk Minimization Approach for Radiation Hazards

The risk of a serious radiation injury from BNL accelerators, including TVDG/TTB is insignificant. However, for radiation exposure it is customary to go beyond the scope of hazard analysis to demonstrate that transient events, such as credible beam faults with deuterons or other low-mass ions, do not cause annual radiation dose goals or requirements to be exceeded. The special status of radiation hazards is exemplified in the As Low As Reasonably Achievable (ALARA) requirement in the BNL RadCon Manual that exposure to radiation is to be minimized and driven as far below the statutory limits as is practicable. The radiological areas (Controlled Area, Radiation Area, etc.) are established to control the flow and behavior of workers in each area such that workers receive the minimum radiation exposure coincident with operating the facility, which is the risk, to achieve its authorized research mission, which is the benefit. These areas are designated with the expectation that radiation levels will not exceed certain specified maxima depending on the type of zone. The designated area maxima will be satisfied considering both the base level of residual radiation fields and the integrated effect of the short bursts typical of credible beam faults. The C-A Operations Procedure Manual, in compliance with the BNL Radiological Control Manual, lists the different radiological areas including the required controls to be used at the TVDG/TTB facilities for minimizing exposure to external radiation.

Significant contamination and internal uptake of radionuclides is extremely unlikely and further analyses of these issues are not necessary, and are documented in a Technical Basis for Bioassay.[25]

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[23] Safety Analysis Report for the HITL-to-Booster (HTB) Heavy Ion Beamline, Brookhaven National Laboratory, Upton, New York 11973, October 1991. Please note that HITL-to-Booster (HTB) was renamed Tandem-to-Booster (TTB).

[24] Safety Assessment Document for the Tandem Van De Graaff Facility, Brookhaven National Laboratory, Upton, New York 11973, October 1995.

[25] http://www.rhichome.bnl.gov/AGS/Accel/SND/Bioassay/BioassayTechBasis.pdf Technical Basis for Bioassay Requirements, Collider-Accelerator Department, January 2001.

3.3. Radiological Hazard Identification and Hazard Analysis

This section describes the hazard identification and qualitative hazard analysis for each of the major portions of the TVDG/TTB. The results of the radiological hazard identification and analyses are arranged in table format. See Tables 3.3.a through 3.3.d. The specific radiological hazards assessed were:

- Radiation in uncontrolled areas.
- Radiation in Controlled Areas and radiological areas.
- Radiation from activated beam line components.
- Airborne radioactivity.

In these specific cases, the risk following mitigation was low or extremely low, the frequency of the hazard was medium to unlikely and the risk category was determined to be extremely low.

Table 3.3.a Qualitative Risk Assessment for TVDG/TTB – Radiation in Uncontrolled Areas Due to Deuteron Beam Losses

Facility Name: TVDG/TTB
System: Areas Outside Beam Enclosures
Sub-System: Outside Beam Tunnel, Target Rooms, Control Room
Hazard: Prompt Beam Radiation Outside Beam Enclosures (e.g., on shielding berm)

Event	Credible beam control fault
Possible Consequences, Hazards	Radiation exposure of personnel above established limits
Potential Initiators	Failure of magnet or magnet power supply, inefficient beam tuning

Risk Assessment before Mitigation

Note: "Low" and "Extremely Low" risk levels are considered acceptable.

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

Hazard Mitigation	1. Beam information display and operating procedures. Beam tuned at low intensity. 2. Operator/ Physicist training. 3. Review of radiation safety by C-A RSC. 4. Radiological area postings, fenced gates interlocked with beam. 5. Chipmunk-interlocked beam cutoff on abnormal radiation levels. 6. Periodic inspection of earthen berm to verify integrity.

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 a hazard mitigation system needed for hazard control? Y/N Yes. If Yes, need ASE requirement.

Table 3.3.b Qualitative Risk Assessment for TVDG/TTB – Radiation in Controlled or Radiological Areas from Deuteron Beam Losses

FACILITY NAME: TVDG/TTB
SYSTEM: Inside Beam Enclosures
SUB-SYSTEM: Beam Line Tunnel, Accelerator Room
HAZARD: Prompt Beam Radiation Inside Beam Enclosures

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

Risk Assessment before Mitigation

Note: "Low" and "Extremely Low" risk levels are considered acceptable.

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

Hazard Mitigation	1. Operating procedures. 2. Worker/experimenter training. 3. Review of radiation safety by C-A RSC. 4. Tunnel/target room sweep procedures. 5. ACS door locks and other access controls. 6. Visual alarms initiated by ACS inside beam line tunnel and target room before beam initiation, allowing sufficient time for un-swept individuals to push beam crash button or exit enclosure to stop beam initiation. 7. ACS automatic interlocks to stop beam if access violation occurs. 8. ACS controls critical devices to automatically prevent beam, thus keeping beam out of downstream section with personnel inside.

Risk Assessment Following Mitigation

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

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

Table 3.3.c Qualitative Risk Assessment for TVDG/TTB – Radiation from Activated Components

FACILITY NAME: TVDG/TTB
SYSTEM: Activated Components
SUB-SYSTEM: N/A
HAZARD: External Radiation from Activated Components

Event	Worker/experimenter inside target room or tunnel during beam off periods
Possible Consequences, Hazards	Unnecessary external dose
Potential Initiators	Improper work planning, procedure violation

Risk Assessment before Mitigation

Note: "Low" and "Extremely Low" risk levels are considered acceptable.

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

Hazard Mitigation	1. Beam tuning to keep activation of magnets to a minimum 2. Integrated Safety Management program assures proper work planning before authorizing start of work. 3. Radiological surveys of work areas performed and RWP issued before start of work in radiological areas. 4. ALARA design and administrative controls assure doses are well below regulatory limits. 5. C-A ALARA Committee reviews of high dose and dose rate jobs. 6. Worker/experimenter training. 7. Residual dose rate levels are very low and radiological postings warn personnel of high dose rates.

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 a hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

Table 3.3.d Qualitative Risk Assessment for TVDG/TTB – Airborne Releases

FACILITY NAME: TVDG/TTB
SYSTEM: Insulating Gas System
SUB-SYSTEM: Exhaust Systems
HAZARD: Exposure to Airborne Radioactive Materials

Event	Uncontrolled release of airborne radioactivity due to release of activated insulating gas
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 before Mitigation

Note: "Low" and "Extremely Low" risk levels are considered acceptable.

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

Hazard Mitigation	1. Integrated Safety Management program assures proper work planning before authorizing start of work. 2. Worker training. 3. Review of airborne hazards by RSC. 4. NESHAPs review. 6. BNL Environmental Management System. 7. Very low levels of radioactivity are created.

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 a hazard mitigation system needed for hazard control? Y/N No If Yes, need ASE requirement.

3.3.1. Radiation Hazards

Since deuterons are the limiting case for radiological hazards from low-mass ions, fault calculations for TTB shielding and activation are based on fluxes associated with 12 MeV deuterons. For routine and fault operations, calculations are given in Appendix 2. Since beam is enclosed in a vacuum pipe and is not of sufficient energy to penetrate the pipe, direct exposure to primary beam is not a hazard.

The principal radiation hazards associated with deuteron operation are listed in order of importance, these hazards include:

- Exposure to secondary radiation created by primary beam losses during normal operation or episodes of abnormal losses.
- Exposure to residual radiation induced in machine components
- Exposure to airborne activated materials.

3.3.2. Source Term

In estimating the degree of radiation risk, the shielding was designed by assuming the routine and maximum operating beam for the facility indicated in Appendix 1. Specifically, the TTB shield and the TTB current monitoring device are designed to mitigate the greatest radiation hazards from low-mass ions. The shield alone is more than adequate for protection against high-mass heavy-ion losses because heavy-ion beam intensity and/or individual nucleon energies are much less by comparison.

To date, the beam accelerated in RHIC has not begun to approach that of the "mature machine"; however, the needs of RHIC for future running were adopted. Deuterons in RHIC were not explicitly considered, but one assumes that explicit proton numbers used for "unfolding" the nucleon-nucleon effects in heavy-ion collisions are suitable. Under this assumption, the total annual deuterons are about 7E17. This accounts for normal beam losses and deuteron beam tuning in Tandem, TTB, Booster, AGS and AtR.

When the TTB line is delivering beam to downstream users, a 10% beam loss has been observed. No specific points of chronic loss have been identified, and the distribution of these losses is not known. When the TTB line itself is being tuned, beam loss is inherent in the tuning process as wire chambers and Faraday cups are inserted at various places in the line. Adding these losses gives a total loss estimate at a single point of about 2E16 deuterons per year (see Appendix 1). The maximum incremental loss at a single point was estimated to be about 4.5E13 deuterons in one hour.

3.3.3. Results of Calculation for Radiation Levels

The normal running current in the TVDG accelerator room is planned to be 67 nA of deuteron beam at 12 MeV. The normal terminal voltage is planned to be 6 MV. For a full-energy beam fault, radiation levels from deuterons could fault to about 50 rem/h at one foot at 0^o from a 30 MeV deuteron beam that would result from a voltage fault of 15 MV. For a full-intensity beam fault, the radiation level could fault to 230 rem/h at 1 foot at 0^o if the current is intentionally tuned to maximum 10 μA. Thus, dual redundant interlocks are required in the TVDG accelerator room. It is noted these fault conditions require two events: an intensity or voltage fault and stopping the beam at a single point. These radiation levels are summarized in Table 3.3.3.

Table 3.3.3 Calculated Radiation Levels in the TVDG Accelerator Room and the TTB

Description	Deuteron Current	Terminal Voltage	Instantaneous Radiation Level at 1 foot at 0^{o}, rem/h
TVDG Normal Beam, Point Loss (single fault)	67 nA	6 MV	1.5
TVDG Full Energy Beam, Point Loss (double fault)	67 nA	15 MV	50
TVDG Full Current Beam, Point Loss (double fault)	10,000 nA	6 MV	230
TTB Normal Beam, Anticipated Beam Loss (routine loss)	6.7 nA or 10% in transit to RHIC 4.5E13 deuterons for one hour at a point	6 MV 6 MV	0.15 0.04
TTB Normal Beam, Point Loss (single fault)	67 nA	6 MV	1.5
TTB Full Current Beam, Point Loss (double fault)	200 nA	6 MV	4.5

3.4. Hazard Controls

The purpose of this section is to briefly summarize the various system features and administrative programs that help to control hazards or the minimize risk of various hazards resulting from low-mass ions in the TTB and TVDG.

3.4.1. Radiation Protection

The significant hazard at the TVDG/TTB during deuteron operations is ionizing radiation, and operations are planned to be within DOE dose guidelines. The Department uses a graduated system of shields, fences or barriers, locked gates, interlocks and procedures to match access restrictions with potential radiation hazards that satisfies both the BNL and DOE requirements.

3.4.1.1. Permanent Shielding and ALARA Dose

Although the Laboratory site is a limited access site, service personnel from off-site or BNL non-radiation workers may work near the accelerators or may traverse the complex. The Laboratory policy is to restrict the dose to 25 mrem per year to such personnel. The C-A Department adheres to this policy by using shielding and radiation monitoring devices that prevent radiation levels from exceeding set points. Based on the fault study results listed in Appendix 5 and calculations in Appendix 2, the uncontrolled areas outside of the TTB meet the less than 25 mrem per year requirement.

For the minimum thickness of 3 ft, the normal operating loss described in Appendix 1 yields 64 μrem in an hour. An occupancy factor of 1/16th is a traditional assumption for such an area,[26] and it yields 84 work-hours for an 8-week running period. This gives a yearly dose estimate of 5.3 mrem for an individual. These dose rate and annual dose estimates fall within the definition of an uncontrolled area. In addition, fault studies indicate calculations overestimate the dose rate by a factor of 1.9 at a depth of 2.7 ft and a factor of 5.5 at a depth of 3.6 ft. If one divides the 3 ft soil estimates by 1.9, then the results become 34 μrem in an hour and less than 3 mrem in a year.

3.4.1.2. Permanent Shielding Materials

The permanent bulk shielding materials for the TTB and TVDG are primarily materials used at existing BNL accelerator facilities. For example, concrete and earth provide protection for personnel outside the TTB tunnel and in the TVDG target rooms. In addition to these materials, paraffin, borated paraffin, polyethylene, borated polyethylene and Pb may be used for local shielding and in special circumstances. Shielding configuration is closely controlled and may not be changed without review and approval of the C-A Radiation Safety Committee (RSC).

In reviewing radiation shielding associated with deuteron running, it was determined that shielding was needed at the beam openings to Target Room 1 to prevent scattered secondary beam from entering that area. This shielding was installed. Calculations and a fault study were also performed to see if the northwest corner of the Tandem Control Room was sufficiently shielded for proton and deuteron running at full energy and current. In order to maintain ALARA, either shielding will be added to this location, or a Chipmunk will be added in the control room as an area-radiation monitor during proton or deuteron running. At least part of the Tandem Control Room may become a Controlled Area. Finally, a survey of earth shield areas along the TTB beam line was performed. Part of the earth shield was found to be less than 3 feet. These soil shields have been raised to 3 feet thickness or more.

3.4.1.3. Radiation Detection and Radiation Interlocks

Protection for workers is accomplished partly through a safety interlock system. Based on fault levels, dual redundant interlocks are required in the TVDG accelerator room. A second set of switches was added on outside gates; that is, dual interlocks are on the mechanical equipment room, control room, Target Room 4, TTB, downstairs electrical equipment room and

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[26] NCRP, see footnote 3.

downstairs mechanical equipment room gates. This is a simple loop with all gates in series. It is fully independent of the existing Tandem radiation safety system. Since this second string is much less flexible than the existing system, it is used only for low-mass ion running. An additional switch allows a redundant target-room door switch to be tied into the interlock string as well, in cases when protons or deuterons are delivered to a TVDG target room.

In addition to interlocks, two new beam stops were added at the low energy end of MP6 and two at the low energy end of MP7. These beam stops are the critical devices that will inhibit the beam should door interlocks or radiation levels trigger an interlock.

Hardware was also added to limit the beam steered to the TTB. The limit on deuteron beam energy at 12 MeV is done by limiting the field in bypass dipoles that direct the beam out of MP6 and around the back of MP7 prior to steering the beam into TTB. Radiation Safety Committee approved units that limit currents were placed on two magnets. These magnets limit the energy for deuterons coming from MP6, which will be the normal deuteron running-mode. An "equivalent" method will be used to limit deuteron energy if beam has to be delivered from MP7.

The limit on deuteron beam intensity steered into TTB is maintained by administratively locking in a harp in a selected location in the bypass line during deuteron running, and placing redundant Chipmunks near the inserted harp. Chipmunk trip-levels are set such that if the deuteron current above about 100 nA, then beam stops are inserted. It is noted that the beam size has to be large at the certain locations in order for bypass-line transmission to be reasonable, and the harp will be placed at one of these locations in order to guarantee that the harp always intercepts beam. It is noted that the harp may be replaced with an equivalent beam current monitor following approval by the RSC.

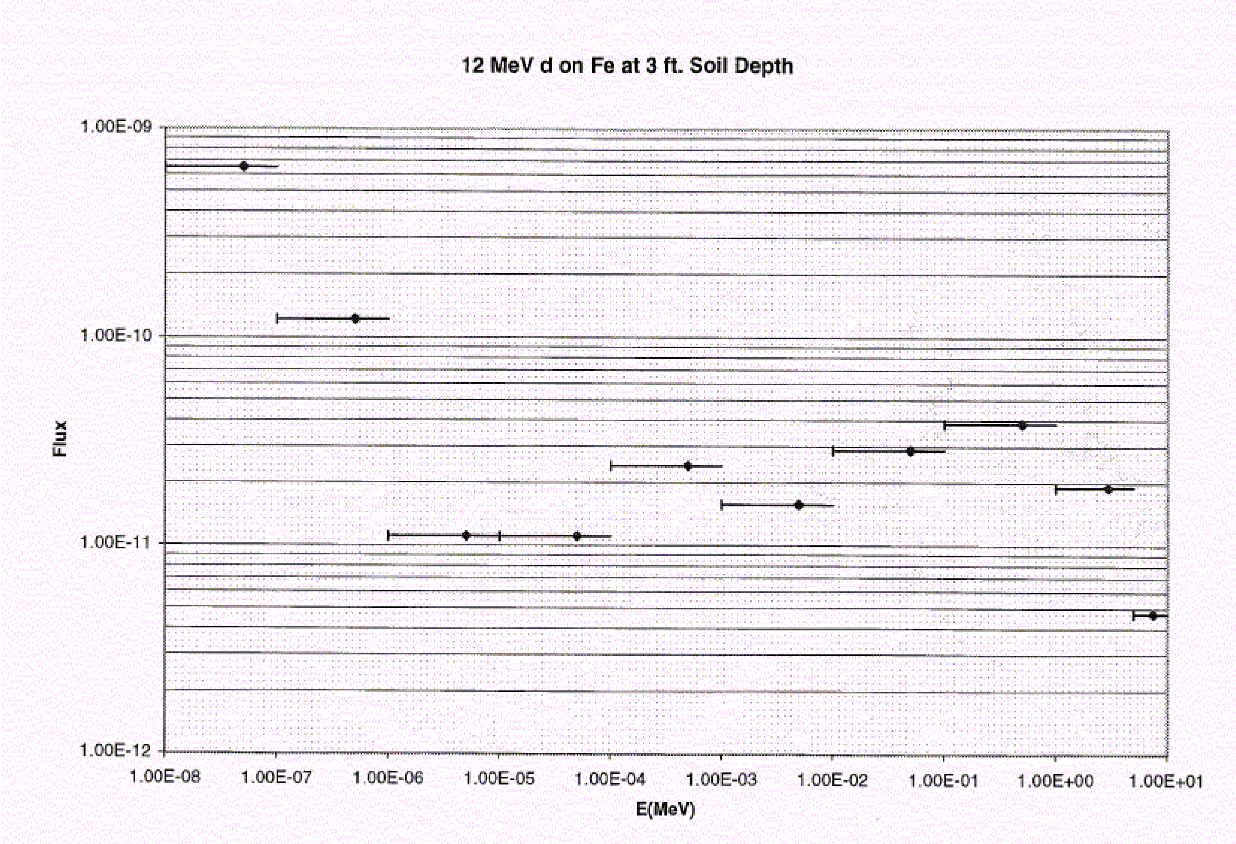
The harp transparency is approximately 85%. Thus, a 15% interception of 100 nA (15 nA loss at 6 MeV/amu), results in 15 mrem/h at 1 m at 90^{O}. The interlock trip level on the Chipmunks will be at about 25 mrem/h. Therefore, the TTB fault level will be limited to about 200 nA at 6 MeV/amu, which results in a maximum level of about 4.5 rem/h at 1 ft at 0^{O} from a fully stopped beam. For this maximum radiation level, redundant interlocks in TTB are not required as per requirements of the Radiation Safety Committee (OPM 9.1.11, Guidelines for Radiological Controlled Area Classification and Radiation Access-Control System Application) or BNL Standards (ESH 1.5.3 Interlock Safety for Protection of Personnel, Rev. 1).

3.4.1.4. Personnel Dosimetry

As seen in Figure 3.4.1.4, the neutron population outside shielded areas from potential beam losses will mostly consist of low-energy neutrons. This spectrum was calculated using the MCNPX code, an iron valve as a target, and 3 feet of soil shielding.[27] The Radiological Controls Division has determined that the BNL personnel TLD is adequate for monitoring such neutron exposures. RCTs are aware of the potential for under-response by the HP1010 survey meter, however. This meter is in use for routine neutron surveys throughout C-A facilities. A correction factor for HP1010 under-response was employed during fault studies (see Appendix 5). This correction factor, a factor of 2, was estimated based on employing a BF_3-based thermal-neutron meter to determine the low-energy neutron dose rate in addition to the dose rate from neutrons measured by the HP1010 survey meters during the fault studies.

[27] A. Stevens, C-A Department.

Figure 3.4.1.4 Neutron Energy Spectrum Above Soil Shielding Due to Deuteron Loss in the TTB



3.4.1.5. Access Controls

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

It is noted that the TVDG and TTB Access Control System documentation and testing procedures are in transition from procedures performed exclusively by the TVDG staff to procedures performed by the C-A Department's Access Controls Group. This transition includes translating TVGD procedures and functional testing into C-A Department testing formats, drawings and records. While this process is completed in the next few months, the basic design principles of the TVDG and TTB Access Control System will be examined to ensure they are similar to design principles used in other C-A Department accelerator facilities. These design principles are:

- Either the beam is disabled or the related security area is secured when radiation levels require it.
- Only wires, switches, relays, PLCs and active fail-safe devices, such as Chipmunks, are used in the critical circuits of the system.
- The de-energized state of the relay is the interlock status; that is, the system is fail-safe.

- Areas where radiation levels can be greater than 50 rem/h require redundancy in disabling the beam and in securing the radiation area.
- If a beam fails to be disabled as required by the state of its related security area, then the upstream beam would be disabled; that is, the system has backup or reach-back.

The C-A Radiation Safety Committee reviewed and will continue to review changes to the interlock systems at TVDG and TTB. See Appendix 8. The Radiation Safety Committee at C-A checks for compliance with requirements in the BNL RadCon Manual, Standards Based Management System requirements and C-A Operations Procedure Manual procedures. It is noted that a Representative of the BNL Radiological Controls Division is a member of the C-A Radiation Safety Committee. Additionally, the C-A Radiation Safety Committee defines the design objectives of the security system and approves the logic diagrams for the relay-based circuits. Cognizant engineers sign-off on wiring diagrams and the C-A Chief Electrical Engineer approves each diagram. The C-A Access Controls Group maintains design documentation.

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

3.4.2. Safety Reviews and Committees

Standing safety committees, as described in Section 2.4.3, are utilized throughout operations to focus expertise on safety, environmental protection, pollution prevention and to help maintain configuration control.

3.4.3. Training

Worker training and qualification is an important part of the overall ESH plan for C-A Department. Training and qualification of workers is described in the OPM and the required training for individuals is defined in the Brookhaven Training Management System (BTMS). All personnel will require an appropriate level of training to ensure their familiarity with possible hazards and emergency conditions.

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

3.4.4. Personal Protective Equipment

There are no predicted radiological hazards that require personal protective clothing unique to the TVDG/TTB for low-mass ion operations.

3.4.5. Control of Radiation and Radioactive Materials

3.4.5.1. Control of Direct Radiation

Shielding is used to reduce radiation levels in occupied areas to acceptable levels. The C-A Department's shielding policy is given in Appendix 6. Potential access points into areas where personnel are prohibited during operations are controlled by the Access Control System. Areas with elevated radiation levels that are accessible to personnel are posted in accordance with BNL RadCon Manual requirements, and individuals are appropriately trained before being granted unescorted access to Controlled Area or radiological areas.

Individuals entering areas posted for direct radiation will have appropriate dosimetry and will have appropriate authorization to enter into and perform work in radiological areas. Periodic radiological surveys during operations will confirm that postings are appropriate. Exposure of personnel to radiation will be controlled through the combination of exclusion from areas with immediately hazardous radiation levels and postings that inform workers of hazards in accessible areas.

3.4.5.2. Control of Radioactive Materials

When the beam is turned off, the remaining radiation hazard comes from activated material and sources. Activated material may be a direct radiation hazard, and may have removable contamination. Based on Appendix 2, the best estimate of activation is that a few beam line components are likely to be tens of microrem per hour at 1 foot after an eight-week deuteron run is completed. Measurements on valves that were targets during the fault study using deuterons show several hundred microR/h on contact. This activated material would not be dispersible unless it is heavily corroded, which is not likely. All known or potentially activated items will be treated as radioactive material and handled in accordance with BNL RadCon Manual requirements. Unlabeled radioactive material that is accessible to personnel will be in an appropriately posted radiological area. Suspect radioactive material will be surveyed by a qualified person before release and then controlled in accordance with the survey results. Process knowledge may also be used to certify items being removed from radiological areas as being free of radioactivity. Known radioactive materials will be appropriately labeled before removal from an area that is posted and controlled. Radioactive items with removable contamination on accessible surfaces will be packaged before removal from posted radiological areas. Workers whose job assignment involves working with radioactive materials will receive documented training as radiological workers.

Based on Appendix 3, radioactive contamination is produced in the TVDG insulating gas by the deuteron beam. For 8 weeks of deuteron operations, it was estimated that less than 200 dpm per 100 cm^2 of P-32 contamination would remain on the walls of MP6. This estimate assumed contamination adhered to the tank walls and did not remain with the insulating gas as the gas moved back into storage cylinders. Most likely, the contamination will remain dispersed in the gas. According to the BNL Radiological Control Manual, the designation "Contamination Area" applies if the removable surface contamination is greater than 1,000 dpm per 100 cm^2. The Radiological Control Technicians will check for contamination following deuteron beam running when the accelerator tank is opened for entry.

3.5. Routine Credible Failures

Routine credible challenges to controls associated with worker protection and with environmental protection are further detailed in Appendix 2.

Deuteron beam losses in the TVDG/TTB enclosures are sufficiently attenuated by the bulk shielding for expected routine operation. Adequate shielding is provided to meet requirements established by the Laboratory for permissible exposure to radiation workers and to members of the public during normal machine operations. Present shielding designs reduce all normal radiation levels to well below the DOE ALARA guidelines.

Exposure to nearby facilities is less than 25 mrem per year and much less than 5 mrem per year at the site boundary, which are the Laboratory guidelines for radiation exposure for nearby facilities and the site boundary, respectively. Radiation exposure to maintenance workers is reduced through the design of equipment to simplify maintenance and the selection of materials to minimize failures. In particular, equipment at high loss points such as beam stops receive detailed examination to assure that radiation exposure received in passing and during the maintenance of these components is kept ALARA. Through such reviews, it is reasonable to expect that maintenance activities be controlled to maintain radiation exposures well within the DOE annual limits, limits that are 5 to 20 times higher than the Department's ALARA guidelines.

There are no gaseous, liquid or dispersible quantities of radioactive materials, except for the radioactivity induced in MP6 insulating gas. Experience indicates that up to several hundred cubic feet (3%) of insulating gas may leak into air each year. However, the level is so low that no off-site threats to the public are anticipated even if all the insulating gas were lost. See Appendix 7.

3.6. Maximum Credible Beam Fault

Not all deuterons will be transported cleanly through TTB; some may be lost during transport. The Department's design goal of no more than 20 mrem per full-fault and the limit of no more than 25 mrem per year are adhered to by the use of shielding and a beam-current monitoring system.

Two Chipmunks will continuously monitor the beam current. Because the maximum current desired for Booster and AGS tuning is 100 nA dc equivalent, the Chipmunks will be set to alarm at 120 nA and will insert beam stops at the Tandem at 200 nA. The worst fault would then be a scenario where slightly less than 200 nA would exist simultaneously with an unnoticed valve closure and an unnoticed alarm. If this situation exists for an hour adjacent to a minimal berm thickness of 3 ft of earth, then the MCNPX estimate, corrected downward by the 1.9 factor from the fault study result as discussed in Appendix 2, would give 3.3 mrem in an hour, which is less than the design goal of no more than 20 mrem per fault. It would take seven such occurrences in a year to reach the 25 mrem per year limit even without considering occupancy. This is not considered credible.

This area may be further protected by radiation monitors, which are part of the Access Control System (ACS) that turns off the radiation source within 9 seconds of detecting a fault condition. It is noted that placement of an array of Chipmunk radiation monitors to catch a random fault anywhere along the beam line is not the intended strategy. Arbitrary losses may likely be detected, at least at some level, by active Chipmunks deployed inside the TTB. However, the use of Chipmunks for this purpose will be determined by the Radiation Safety Committee based on future fault studies.

Experience at C-A shows that use of 1) thick shielding along the beam line, 2) ALARA tuning procedures, 3) beam-current monitoring alarms in the Control Room and 4) procedures that call for response to beam-current monitoring alarms are sufficient to protect personnel in locations not directly monitored by Chipmunks.

Operators would detect the problem immediately due to alarms and due to the resultant radiation-monitor interlock that turns the beam off. Operators are trained to investigate these events according to written procedures, correct the problem if appropriate, record the event for management review, and to discontinue operations if appropriate. Given the duration of these events, a few seconds or less, and the frequency of these events, several times during an annual running period, the on-site and off-site radiation impact is essentially nil, as shown by ambient radiation monitoring of similar accelerator operations by the Environmental Services Division.[28] Due to the action of interlocking Chipmunks and the short-term duration of the fault, the dose to personnel near the facility, sky-shine dose or soil activation are insignificant.

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

3.7.1. Radiation Risks

The routine radiation dose to workers, which is a surrogate for risk, is well below the DOE regulatory limits of 10CFR835. The range of doses received by C-A radiation workers in CY2000, which is the most recent complete data set for a year, is shown in Figure 3.7.1. Experience shows average exposure of C-A radiation workers is about 30 mrem per year. The dose to an average C-A radiation worker is only a small fraction of the regulatory limit, and the increase in fatal cancer risk after a lifetime of radiation work, 50 years, is insignificant, 0.06%[29] compared to the naturally occurring fatal cancer rate of nearly 20%. The risks to the public are an extremely small fraction of worker risk; a factor of over 1,000,000 times smaller.

Worker dose, even including the maximum credible beam fault dose on a frequent basis, would not cause deterministic effects such as burns or tissue damage unless an individual were inside the beam enclosures for several hours during operations involving significant beam losses. The Access Control System, which is categorized as Safety Significant, and the proper execution of sweep procedures assure that such irradiations are not credible.

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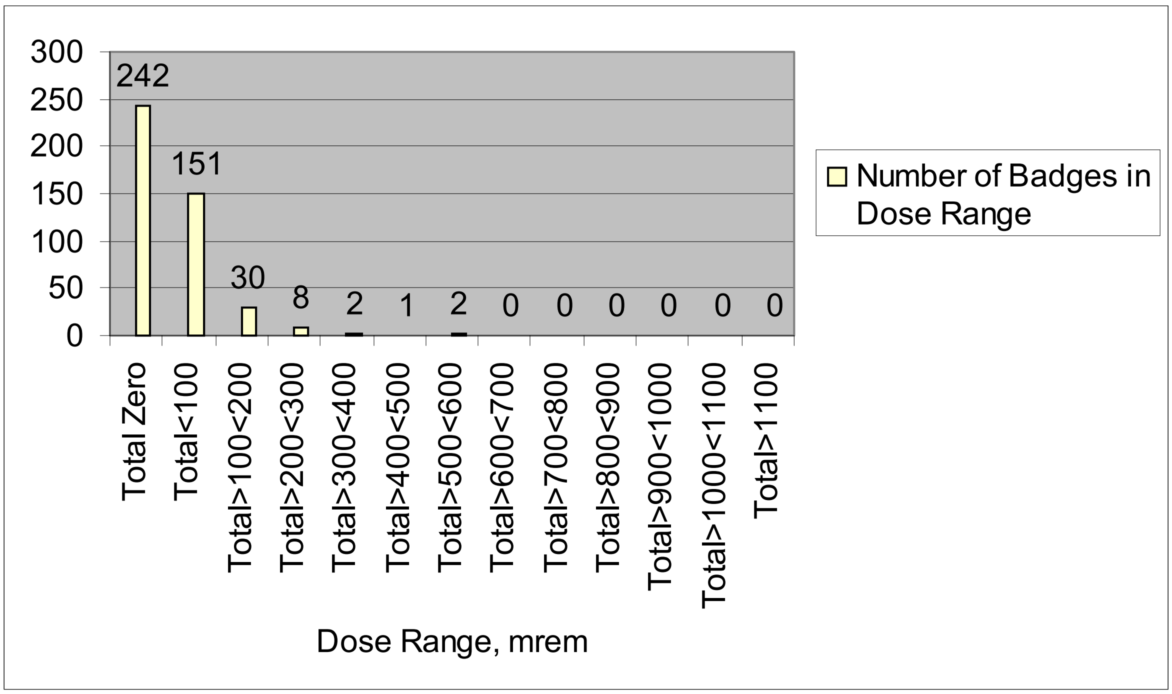
[28] For example, see Chapter 8 of the 1999 BNL Site Environmental Report.

[29] This assumes a risk coefficient of 4×10^{-4} per rem for workers from NCRP Report No. 115, Risk Estimates for Radiation Protection (p. 112) and a 50-year career at 5 rem per year.

Based on the system for formal design review by C-A committees, formal training programs, formal operations procedures, formal quality assurance programs for equipment, and the extensive use of shielding and access controls, the probability of a "catastrophic" radiation exposure is extremely improbable; that is, the probability for this consequence cannot be distinguished from zero.

Figure 3.7.1 Range of Radiation Worker Dose at C-A Department for CY2000



3.7.2. Environmental Risks

The only credible risk to the environment is groundwater contamination. This may be caused by excessive activation of soil. Rainwater may leach the contamination into the aquifer. Appendix 2 indicates the upper limit to soil activation from deuteron running. Current BNL policy requires mitigation such as a soil shield cap to prevent rainwater infiltration should there be a potential to exceed 5% of the Drinking Water Standard in groundwater. The upper limit calculated for soil activation shows a level of about 0.01% of the Drinking Water Standard might be attained. Thus, soil activation from deuteron running is not considered to have any significant environmental impact.

An extensive groundwater-monitoring program has been instituted to verify the effectiveness of beam control procedures. In accordance with DOE Order 5400.1, General Environmental Protection, groundwater quality down gradient of the TVDG/TTB area will be verified by periodic sampling of groundwater surveillance wells. Groundwater samples will be tested for tritium and sodium-22 to verify that the beam control is preventing significant activation of soil. Sampling frequency for the wells will be defined in the annual BNL Environmental Monitoring Plan. The detection of unexpected levels of tritium and/or sodium-22 in groundwater will be evaluated in accordance with the BNL Groundwater Protection Contingency Plan.

There is no credible risk to the environment from activation of water in buried water lines or in storm sewer lines near the TTB. A review showed there was no cross-section on oxygen in H_2O for the production of tritium by neutrons at energies available in the TTB.

There is no credible risk to the environment from airborne releases. Calculations in Appendix 2 indicate only trace levels of Ar-41 are likely to be produced from activation of air in the TTB and Tandem accelerator room, and these levels are not likely to be measurable. Calculations in Appendix 7 indicate airborne release of activated insulating gas has insignificant impact off-site.

3.8.Professional Judgment Issues

The initial screening of TVDG/TTB radiological hazards was performed using qualitative engineering judgment. The C-A engineering, operating and safety staff has many years of experience with BNL accelerators. This experience influenced the analyses.

Appendix 2 describes the bases for conservative maximum hourly routine and faulted beam energy limits which have been used as the bases for the shielding and ALARA analyses. The judgment issues are verified by fault studies.

3.9. Methods Used in Evaluation of Radiological Hazards

Techniques employed in the evaluation of radiological hazards include the use of empirical formula, and the Monte Carlo Programs MCNPX.[30] MCNPX is probably the most widely used neutron transport Monte Carlo code. Several MCNPX calculations have shown excellent agreement with empirical formula.[31]

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

[31] K. Goebel, G.R. Stevenson, J.T. Routi, and H.G. Vogt, "Evaluating Dose Rates Due to Neutron Leakage Through Access Tunnels of the SPS," CERN LABII-RA/Note/75-10 (1975).

4. Decommissioning Plan

4.1. Introduction

The objective of the decommissioning plan, which will be developed near the end of the TVDG/TTB operating lifetime, will be 1) to determine the hazards and risks posed by decommissioning and 2) to plan the activities required to complete the decommissioning. Ensuring the safety of the workers, protecting the public and the environment and complying with applicable state and Federal regulations are of utmost importance in preparing the plan. Management of the operating waste, or other hazardous materials that might remain in the TVDG/TTB after shutdown, as well as the waste generated during the decommissioning activities are key to conducting safe decommissioning. An approach that accurately identifies the types and quantities of these materials, thereby establishing the baseline, is an important aspect of the decommissioning plan.

Another aspect of the decommissioning plan will be the determination of the final site configuration, or end-point, in which the facilities, or site, will be left. Determining the desired product, as well as the risks present, are essential to planning the decommissioning. The preferred decommissioning alternative is the Greenfield condition but the following four alternatives should be evaluated for the decommissioning plan: 1) re-use for a similar function, 2) safe storage, 3) Brownfield condition and 4) Greenfield condition. It is assumed that institutional control will remain in place under Federal oversight for a number of years before decommissioning and after decommissioning completion.

Once baseline conditions and volumes of waste to be dealt with are estimated and the alternative end-points are chosen, methods of accomplishing the decommissioning that will meet the end-point goals can be selected. Preliminary estimates of waste, assuming no components are reusable, are 800 cubic meters of low-level radioactive waste, 3000 cubic meters of concrete waste, 70,000 cubic meters of non-activated recyclable steel, 6000 cubic meters of non-activated recyclable copper, 14000 cubic meters of miscellaneous material, and 15,000 cubic meters of SF6 gas that will contain trace levels of C-14 and tritium. The effectiveness of the methods, their ability to keep personnel exposure ALARA and potential for negative impact on the environment are important criteria applied in choosing the decommissioning methods.

Finally, the waste streams to be managed during decommissioning are to be analyzed in the decommissioning plan, their characteristics and volumes estimated, and treatment and disposal options evaluated. There will be multiple waste streams to be managed during the decommissioning of TVDG/TTB. Some will be able to be treated and disposed of locally, such as recyclable metals and concrete waste, while some, low-level radioactive waste and hazardous waste, will be shipped off site for disposal.

4.2. Baseline Conditions

Establishing the expected baseline conditions of a facility at the end of its operating life can be accomplished by estimating the radioactivity levels and physical conditions based on calculations, design features, operating procedures and waste management requirements. The C-A Department operating procedures and records, C-A Environmental Management System, and BNL SBMS subject areas will provide up-to-date and current information on the TVDG/TTB operating history, activation history, environmental impact, and waste generation and disposal history to help establish the baseline conditions. Design features that help mitigate the impact of potentially high activation levels on the baseline are incorporated into the TVDG/TTB design. An example of such a feature is the beam-current monitor and cutoff devices to ensure that beam loss criteria are met thereby reducing inadvertent activation of materials. Design features can potentially have a large impact on the cost of the decommissioning since they will help ensure that large volumes of soil or water will not have to be handled as low-level radioactive waste, and control of the beam will minimize activation of magnets and other beam line components.

Additionally, methods in place in C-A Department operating procedures and management systems that track spills and spill response actions, that record information from beam-loss events, and that record component replacements will aid in establishing the baseline. Records of hazardous or radioactive wastes and personnel radiation dose will be maintained for tracking purposes and will provide additional baseline information. Records to be consulted will include history of equipment, as-built drawings and records of changes from the baseline conditions.

The decommissioning plan will include requirements for characterizing the facility after operations are shut down and before decommissioning begins. This characterization will confirm or re-establish the baseline conditions, will be used in performing a risk assessment to support the decommissioning safety assessment, and will help establish surveillance and maintenance required to maintain the facility in a safe standby mode until decommissioning begins.

4.3. End Point Goals

The overall end-point goals will be stated early during deactivation planning because they will form the basis for specific decommissioning goals and activities that must take place. The goals for the safety basis of the deactivated TVDG/TTB will be established, and determination will be made of decommissioning protection measures.

Determining the desired product, the final site-configuration and the risks present are essential to planning the decommissioning alternatives. The decommissioning plan will address the baseline conditions and consider all the alternatives. The decommissioning alternatives that may be evaluated are: (1) reuse for a similar function, (2) safe storage, (3) Brownfield condition, (4) Greenfield condition. Greenfield means that the site will be returned to its original condition with no remediation or institutional controls required. Brownfield means that some remediation or institutional control will be required such as ground water monitoring. It is assumed that institutional control will remain in effect under Federal oversight for a number of years before decommissioning and a number of years after decommissioning.

The process of determining the alternative that would be most cost-effective and that would provide the least amount of exposure of workers to radiation will involve consideration of the pros and cons of each alternative. For example, beam-line components will be activated and may require some decay time before decommissioning begins. The safest and most cost-effective alternative for the TVDG/TTB facilities will probably be a combination of: 1) removal of activated items, 2) a period of safe storage, and 3) future re-use of components and buildings.

4.4. Decommissioning Methods

Decommissioning methods will be chosen based on radiological conditions at the time of decommissioning and the effectiveness of the methods to achieve the desired end use of the buildings. Additional criteria in choosing the methods are the ability of the methods to keep personnel exposure ALARA and to protect the environment and worker. While decontamination is not a large part of the TVDG/TTB decommissioning, activated insulation gas can become dispersible and decommissioning will require application of standard contamination control techniques. A variety of techniques and removal methods will be analyzed to select the approach that accomplishes the goals and optimizes safety to the workers and protection of the environment as well as efficiency.

The decommissioning plan will describe methods that accommodate varying conditions while maintaining ALARA principles as the basis for the cost estimate. Design features that will reduce personnel exposure as well as decommissioning costs will be addressed. The plan will address the conditions and hazards in detail and will have the benefit of additional information and technologies not yet available. The activation and contamination levels should be known in detail, which will allow determination of protection requirements to prevent unwarranted exposure of the workers to radiation.

4.5. Waste Streams

Recyclable materials and wastes anticipated from the decommissioning operation will be identified in the decommissioning plan. Initially, structures and process equipment will be inventoried. Accordingly, the resulting inventory will be comprised largely of process components and structures that are either potentially recyclable or are solid waste. Based on the general nature of the decommissioning operations and the applicable requirements, an all-inclusive list of waste categories will be identified as part of the decommissioning plan. That list will include recyclable metals and equipment and any beam-line components saved for re-use for completeness even though they might not be classified as solid wastes under the Resource Conservation and Recovery Act. Initial estimates of waste for Greenfield conditions are 800 cubic meters of low-level radioactive waste, 3000 cubic meters of clean concrete, 70,000 cubic meters of clean recyclable steel, 6000 cubic meters of clean recyclable copper, 14,000 cubic meters of clean miscellaneous waste, of which some electrical equipment may be recyclable. Earth-berm soil will be stockpiled and re-graded following tunnel and component removal. Soils containing tritium and Na-22 are included in the 800 cubic meters of low-level radioactive waste. Additionally, 15,000 cubic meters of slightly radioactive insulator gas will have to be dispositioned. Initial estimates of activation of components, assuming a 4 to 5 year decay period before decommissioning, shows no need for remote handling of waste, and it is anticipated that all waste will be contact handled. The decommissioning plan will review this assumption so that safe and efficient waste handling and disposal methods can be determined.

Waste treatment facilities and processes in place at the time of decommissioning will be reviewed as part of the decommissioning plan. Several low-level radioactive waste disposal facilities, such as Hanford, are currently used by the BNL Waste Management Division today, and it is assumed these facilities, or equivalent facilities, will be available in the future. Cost estimates for waste disposal will be made at the time of decommissioning plan development.

4.6. Regulatory Requirements

The decommissioning plan will delineate the applicable New York State and Federal laws, consensus standards, DOE directives and other requirements applicable to the decommissioning activities, especially those required to meet the end-point criteria.

Regulations affecting decommissioning fall into three categories:

- Those that directly affect decommissioning, e.g., the removal of radioactive materials as needed to reduce risk.
- Those that protect the worker and the public during decommissioning operations.
- Those that apply if hazardous or toxic materials are present in the facility.

A number of DOE orders and Federal regulations actually cover two or more of these categories, so there may be overlapping requirements across categories. Sound planning for interacting with the regulatory agencies and compliance with these regulatory requirements is critical to timely and successful completion of decommissioning activities and will be an integral part of the initial planning activities.

Abbreviations

ACS – Access Control System
AGS – Alternating Gradient Synchrotron
ALARA – As Low As Reasonably Achievable
ASE – Accelerator Safety Envelope
AtR – AGS to RHIC Transfer Line
ATS – Assessment Tracking System
BNL – Brookhaven National Laboratory
BSA – Brookhaven Science Associates
BTMS – Brookhaven Training Management System
C-A – Collider-Accelerator
CY – Calendar Year
DC – Direct Current
DOE – Department of Energy
DWS - Drinking Water Standard
ES&F – Experimental Support and Facilities Division
ESH – Environment, Safety and Health
ESHQ – Environment, Safety, Health and Quality
ESRC – Experimental Safety Review Committee
FUA – Facility Use Agreement
ISM – Integrated Safety Management
ISO – International Standards Organization
HTB – HITL to Booster
HITL – Heavy Ion Transfer Line
MCNPX – Monte Carlo Neutron Photon Transport Computer Codes
MCR – Main Control Room
MP6 - Tandem Van De Graaff accelerator designation
MP7 – Tandem Van De Graaff accelerator designation
NCRP – National Council on Radiation Protection and Measurements
NESHAP - National Air Emission Standards for Hazardous Air Pollutants
OPM – Operations Procedure Manual
QA – Quality Assurance
QA1 – Quality Assurance Category 1
R2A2 – Roles, Responsibilities, Accountabilities and Authorities
RadCon – Radiological Control
RCT – Radiological Control Technician
RHIC – Relativistic Heavy Ion Collider
RSC – Radiation Safety Committee
SAD – Safety Assessment Document
SAR – Safety Analysis Report
SBMS – Standards Based Management System
TLD – Thermo-Luminescent Dosimeter
TTB – Tandem to Booster Transfer Line
TVDG – Tandem Van De Graaff

Units

amu – atomic mass unit, a unit of mass
MeV – million electron volts, a unit of energy
microR/h – microRoentgen per hour, a unit of radiation exposure in air
mrad – millirad, a unit of absorbed dose
mrem – millirem, a unit of dose equivalent
nA – nanoampere, a unit of current
μCi – microcurie, unit of radioactivity

Increased neutron dose due to increased deuteron energy in the TTB line

December 15, 2002

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This note is written as a follow-up to the Appendix 2 Deuterons in TTB: Radiological Issues (written by Alan Stevens) in the Safety and Hazard Assessment document **USI 3: TTB SAR, Radiation Hazards from Low Mass Ions in the TTB, 11-15-01**. The purpose is to investigate what the neutron dose equivalents (hereafter called doses) are due to the increased deuteron energy up to 18 MeV (ie. 9 MeV per nucleon) at various depths in soil. This is to be compared with the doses calculated with the assumption of deuteron energy of 12 MeV (ie. 6 MeV per nucleon) in the above-mentioned Appendix 2.

The work was started by first modifying and using Alan Stevens' input file and running the same version of the MCNPX software that Alan has used to reproduce the results shown in the above document. After that, the author has modified the deuteron energy, run a newer version of the MCNPX software and even used a new set of the MCNPX input data file which seems to cover a broader energy range. The latter two steps are not really necessary but it is "a good exercise for the *student*".

The same method and geometry as in the above-mentioned document have been used in all the calculations including the physics options of MCNPX, ie., with and without forcing energy conservation. The results and some explanations are given in the following three figures. The errors in the plots come from MCNPX which may not be the most meaningful as Alan Stevens has commented. Four depths have been used for each set of calculations. The deepest is at 4 feet of soil and the statistics behind 4 feet of soil seem to be insufficient even after 50 million events.

Figure 1 shows the maximum doses due to the transport of 18 MeV of deuteron in the TTB line as a function of depths in soil for both the default physics setting of MCNPX and the setting where energy conservation is enforced. The old version 2.1.5 of MCNPX has been used here. Compared to Figure 2 in Alan Stevens' document, the doses due to 18 MeV deuterons at various depths seem to be about 4 times as much as that of 12 MeV deuterons. A straight line with this factor 4 is shown in this logarithmic plot to be compared with the original line in Alan Stevens' document.

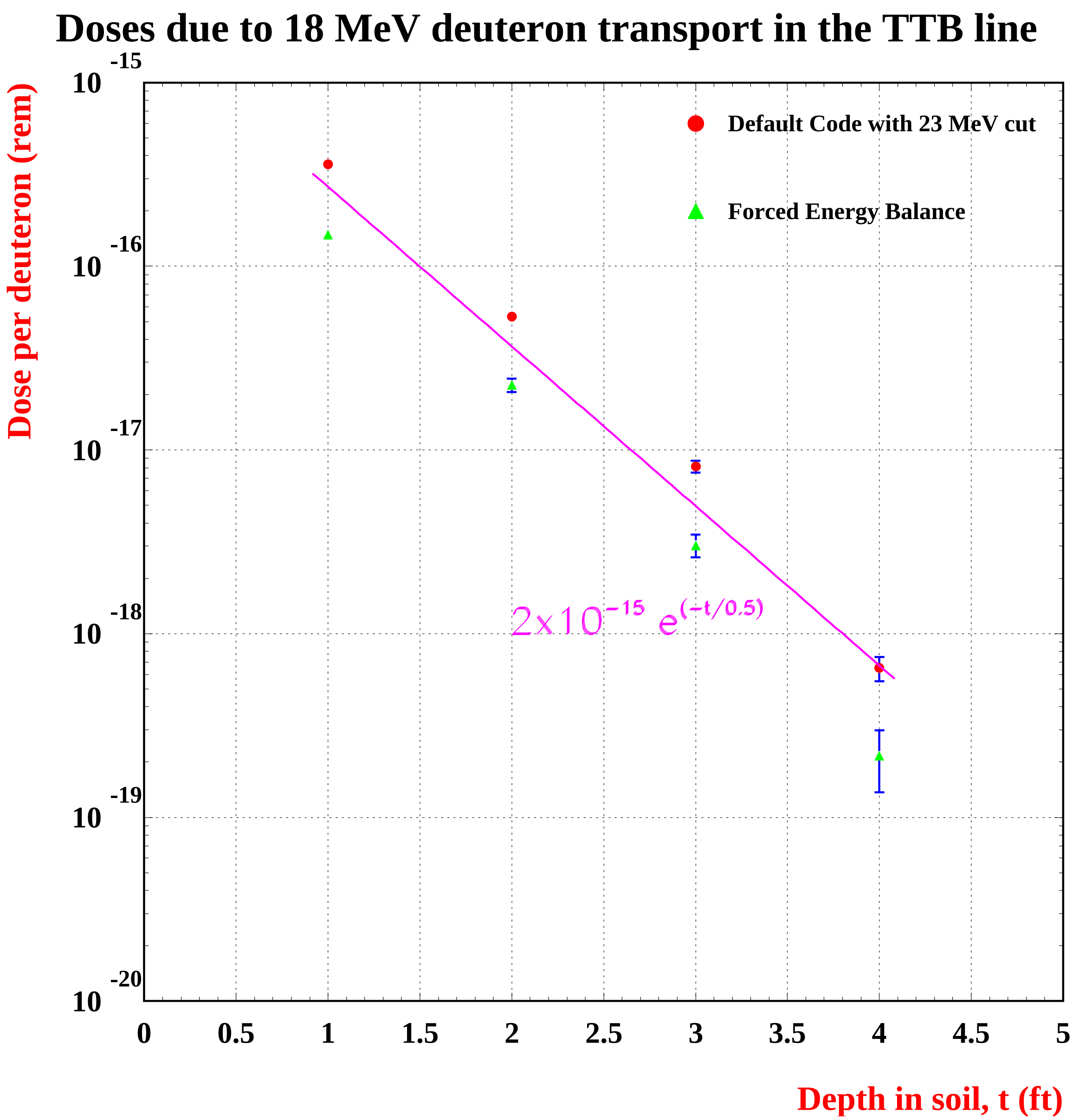

Figure 1 **Neutron dose (equivalent) due to the transport of 18 MeV deuterons in the TTB line at different depths of the soil.**

Figure 2 shows the same radiation dose calculation using two different versions of the MCNPX software and neutron data libraries. The data points in red solid circles show the same doses that are in Figure 1 using the default MCNPX physics settings and the version of MCNPX is *2.1.5*. The data points in green triangles show the results from running the version *2.4.k* of MCNPX. The above two sets of calculations all use the so-called "20 MeV" data (from the ENDF/B-VI evaluation which can be found at http://www-xdiv.lanl.gov/XCI/PROJECTS/DATA/nuclear/avdoc.htm). Since a couple years ago, MCNPX collaboration has provided a new data library at 150 MeV which is available at http://mcnpx.lanl.gov/data.html. The data points in blue empty circles show the dose calculation results using the new 150 MeV data library running the version *2.4.k* of MCNPX. The various calculations seem to agree with each other within errors.

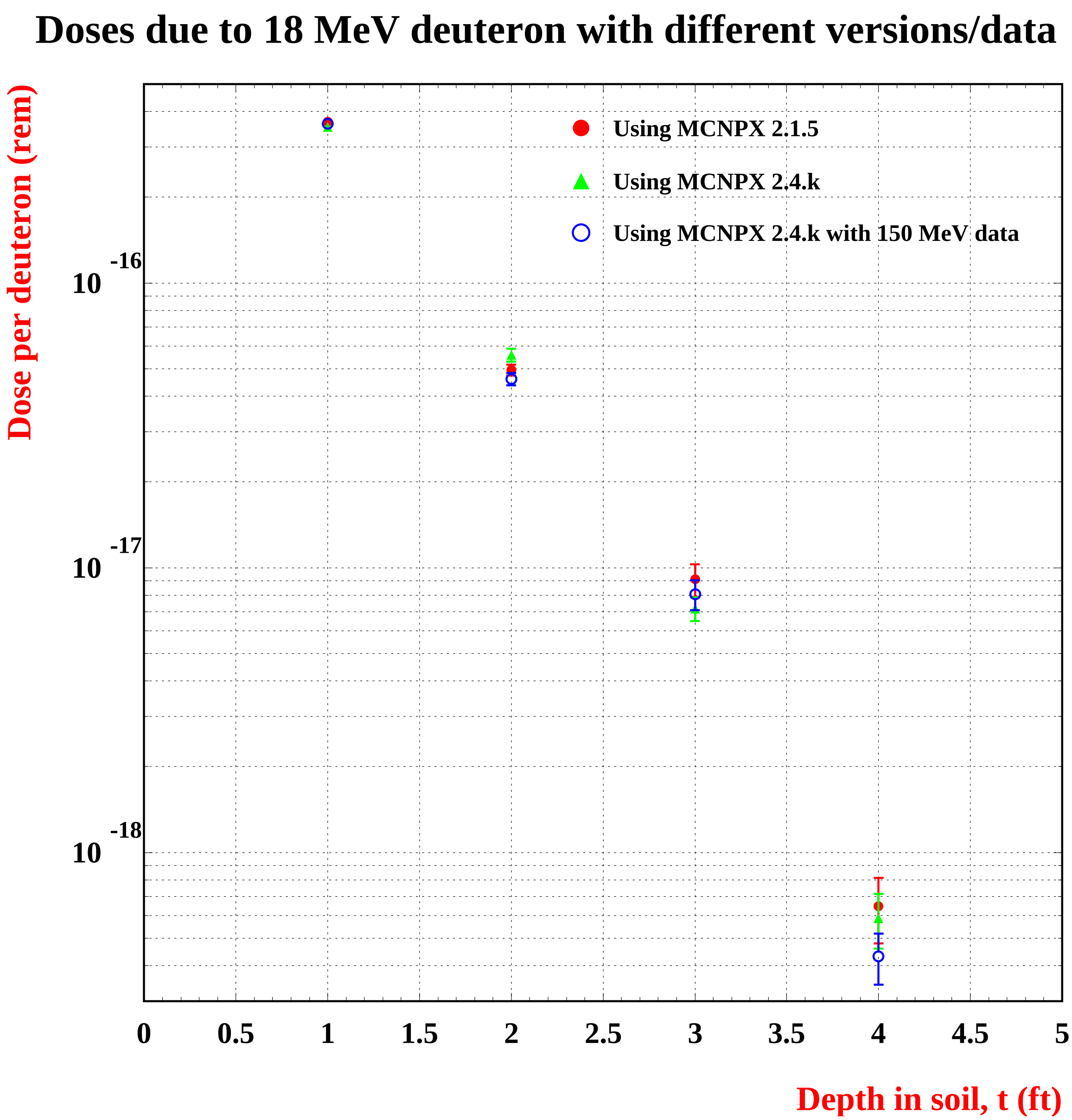

Figure 2 **Neutron dose calculations using different versions of MCNPX software and using different neutron data libraries.**

Figure 3 shows the ratios of calculated neutron doses with an iron (Fe) target to those with a tungsten (W) target with deuteron energies at 12 MeV and 18 MeV. At 12 MeV, the ratios seem be around 5 to 6. (The last ratio at 4 feet of soil is not shown because it is out of scale, 22.6 ± 12.0 and this result may suffer from insufficient statistics.) At 18 MeV, the ratios are roughly 2.

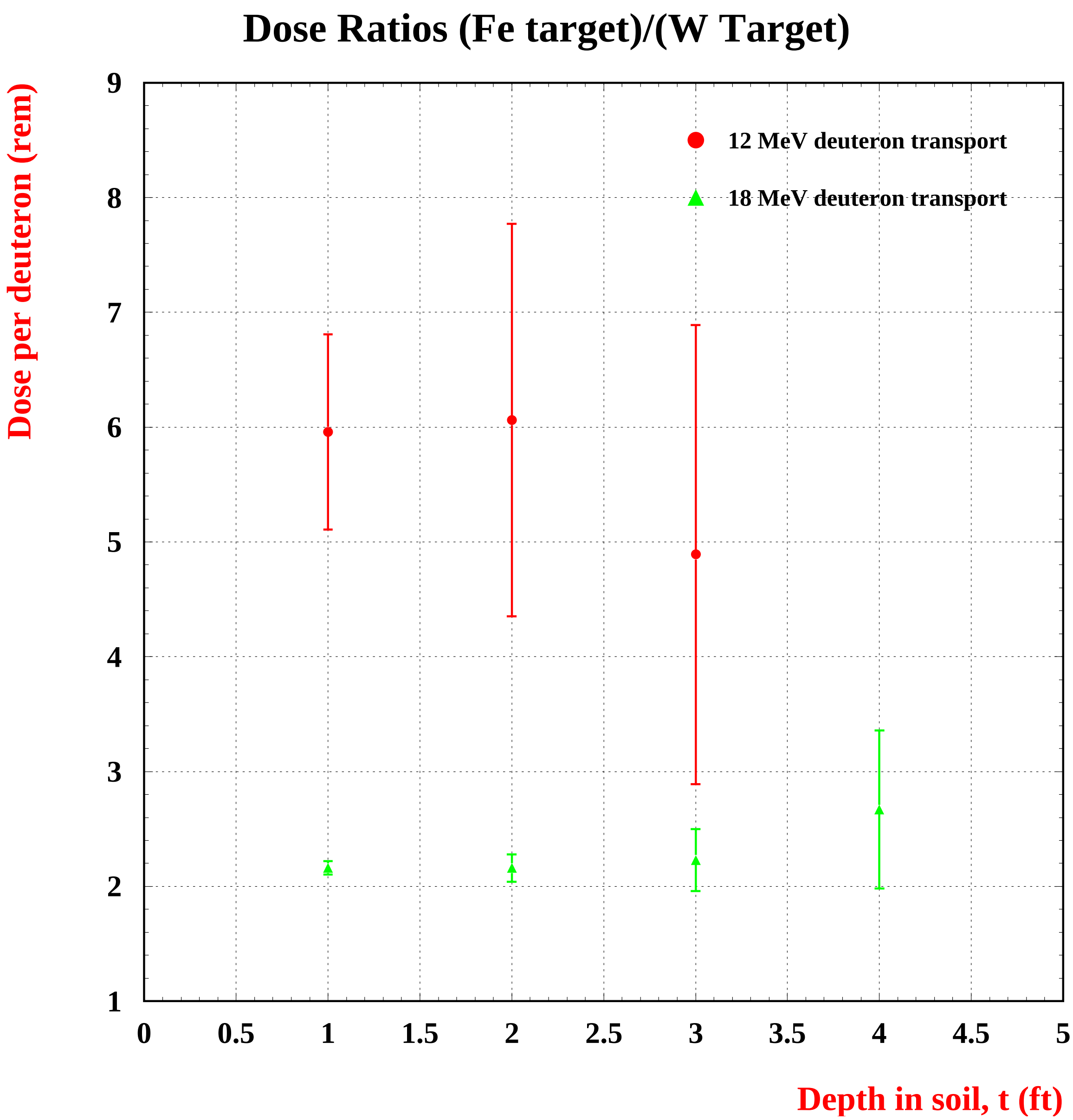

Figure 3 **Ratios of neutron doses with an iron (Fe) target to those of a tungsten (W) target.**