Accelerator Test Facility
Safety Assessment Document
Building 820

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3/8/10

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ACCELERATOR TEST FACILITY SAFETY ASSESSMENT DOCUMENT

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Acronyms

AC	Alternating Current
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ARR	Accelerator Readiness Review
ASE	Accelerator Safety Envelope
ATF	Accelerator Test Facility
BNL	Brookhaven National Laboratory
BTMS	Brookhaven Training Management System
CAMAC	Computer Automated Measurement And Control
CAP	Center of Accelerator Physics
CO2, CO_2	Carbon Dioxide
DC	Direct Current
DOE	Department of Energy
ECR	Environmental Compliance Representative
EMS	Environmental Management System
ESH, ES&H	Environment, Safety, and Health
ESH&T	Environment, Safety, Health & Training
ESR	Experimental Safety Review
ESSH	Environment, Safety, Security, and Health
FEL	Free Electron Laser
FHA	Fire Hazard Analysis
GW	Gigawatt
Hz	Hertz
IH	Industrial Hygiene
ISO	Independent Standards Organization
KV	Kilo-volts
LOTO	Lockout Tagout
LSC	Life Safety Code
MeV	Million electron-volts
MHz	Megahertz
MW	Megawatt
nC	Nano-Coulomb
Nd:YAG	Neodymium: Yttrium Aluminum Garnet
NFPA	National Fire Protection Act
NPH	Natural Phenomena Hazards Mitigation
NRTL	Nationally Recognized Testing Laboratory
NSLS	National Synchrotron Light Source
ODH	Oxygen Deficiency Hazard
OHSAS	Occupational Health and Safety Assessment System
P2	Pollution Prevention
PPE	Personal Protective Equipment
pS	Pico-second
R2A2	Roles, Responsibilities, Authorities, and Accountabilities

RF	Radio Frequency
RMS, rms	Root Mean Square
RWP	Radiation Worker Permit
SAD	Safety Assessment Document
SBMS	Standards Based Management System
SFSP	Strategic Fire Safety Plan
SME	Subject Matter Expert
SOP	Standard Operating Procedures
TLD	Thermo Luminescent Dosimeter
USI	Unreviewed Safety Issue
V	Volts
WP	Work Permit
YAG	Yttrium Aluminum Garnet
μS	Micro-second

1. INTRODUCTION AND DESCRIPTION OF THE FACILITY

The Accelerator Test Facility (ATF) comprises a 120 MeV electron linear accelerator and an experimental area to study advanced acceleration techniques and to carry out research involving free electron lasers and basic electrodynamics. Experiments can take from a few hours to a few years, but a typical experiment takes a few months. The linear accelerator is housed in the low bay area of Building 820, on the east side of Renaissance Road at the intersection of Rutherford Drive, , as shown in Figure 1a below and an experimental area building adjacent to Building 820 shown in Figure 1b, on the following page.

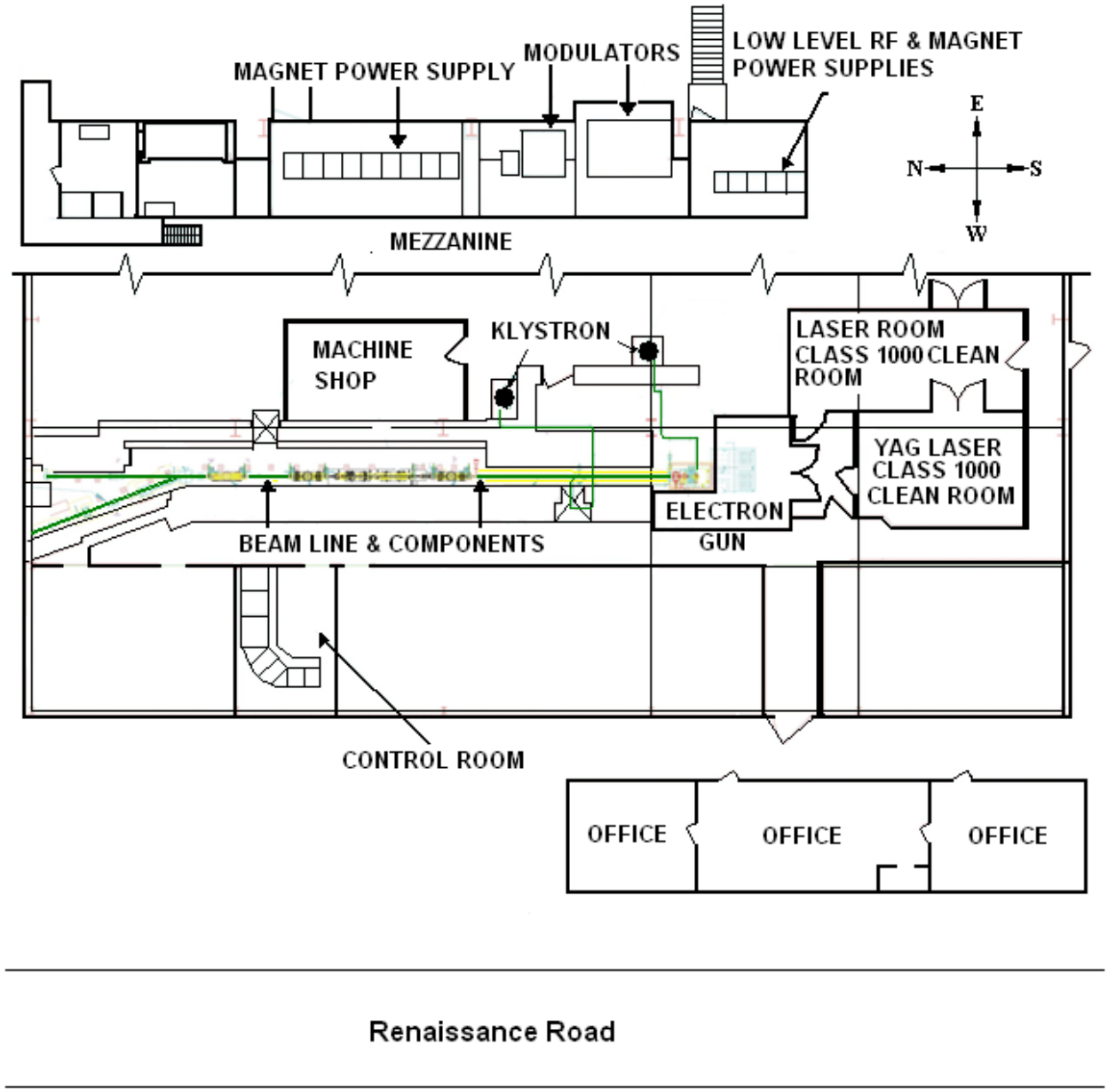

Figure 1a: Accelerator Test Facility, Building 820 Layout

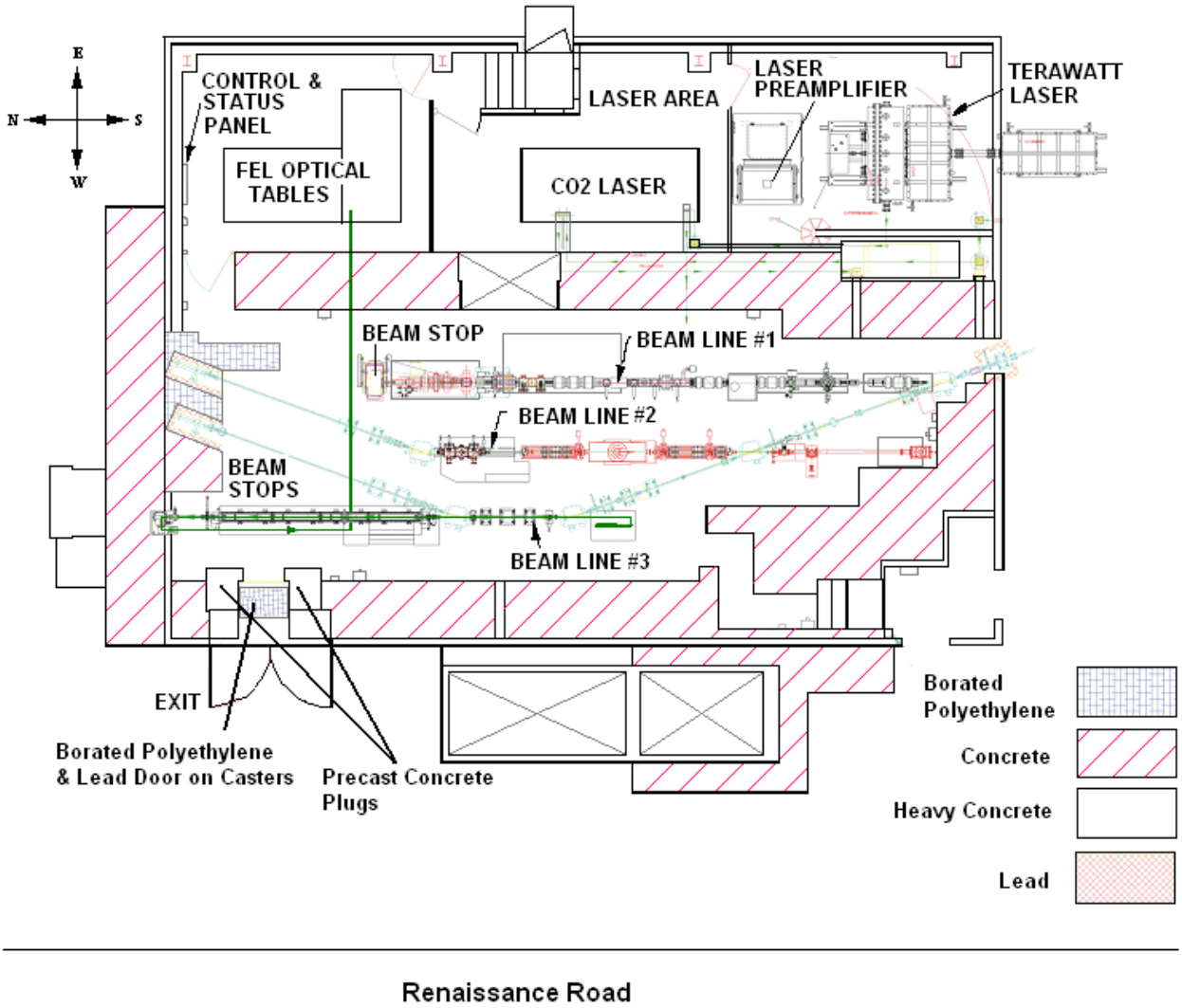

Figure 1b: ATF, Building 820 Experimental Equipment Areas (1 & 1.5 Ft. Thick Concrete Roof over Experimental Area not shown for clarity).

Prior to operation of the ATF a Safety Assessment Report was prepared in 1989, received approval to operate by the DOE, and has been in operation since. Originally part of the NSLS, in May 2002 the ATF was transferred to the Physics Department. The Safety Assessment Document (SAD) and Accelerator Safety Envelope (ASE) that were approved in October 2004 incorporated these changes and this document is an updated version as part of the five year review cycle. It is in compliance with DOE Order 420.2B.

1.1 Description of the Facility

The general arrangement of the building shown in Figure 1a provides for an electron gun with a laser excited photocathode, a low energy beam transport and beam analysis system, two traveling wave linear accelerator sections and a high energy (120 MeV) beam transport and beam shaping system to provide beams appropriate for the experimental program. The experimental area shown in

Figure 1b also houses lasers for experimental purposes. The experimental hall contains three separate beam lines for experimental purposes.

1.2 Worker and Public Safety

In order to protect both workers and the general public, the accelerator and experimental systems are housed in a fully shielded and secured area with appropriate audible and visual signs. There are no exposed electrical systems at voltages greater than 24V except for the 90° Magnet Power Supply which is set to <50Vdc output, and there is no release of radiation or toxic materials that can cause harm to workers or the general public. The high power lasers utilized are also contained in dually interlocked areas requiring key access and are not accessible to the general public. The electron beam is not a source of contamination. There are no routinely generated radiological disposables. Offices for the staff (approximately 10 people) are located away from the Controlled Areas, no dose has been recorded on TLDs for the last 3 years and none is expected.

In addition to its conduct of work planning and control for operations and experiments, the ATF embraces the 5 Core Functions and 7 Guiding Principles of the DOE's and BNL's Integrated Safety Management.

2. SUMMARY/CONCLUSIONS

The shielding design together with the radiation security interlock search and secure procedures ensure that no personnel are exposed to any levels of radiation that would exceed the BNL untrained, unescorted personnel limit of 25 mrem/yr due to the operation of the Accelerator Test Facility at the maximum permitted operation levels.

Design and construction of electrical equipment ensures that no exposed high voltages are present anywhere in the facility. High voltage enclosures are either locked or fully interlocked. Normal policy prohibits working on energized electrical equipment and any deviation from this requires a permit and a procedure. Personnel are trained in these policies and in Lock/Out Tag/Out procedures.

Non-hazardous fluids are used for cleaning purposes where possible and all chemical inventories are kept to a minimum. The ATF generates a minimum amount of hazardous waste. The building has been designed to conform with the National Fire Protection Association "Life Safety Code" No. 101 and DOE Order 420.1B Facility Safety 7/23/04

The high power, pulsed, laser beams are contained in interlocked enclosures or rooms and are transported inside opaque beam tubes. Entry into interlocked laser areas requires the use of protective eyewear as defined in the laser SOPs.

The entire facility may be operated at its permitted operation levels with minimal risk to the safety and health of staff, users or the general public. Hazards and controls are given in the table below.

Hazards	Controls
CONVENTIONAL	Work planning/experimental planning Design Committees and safety inspections Self assessment ATF Procedures BNL SBMS

	Training/retraining PPE Worker feedback Manager commitment to safety Accountability
ENVIRONMENTAL Negligible Soil Activation No Air Activation Waste Regulated Industrial/Universal Hazardous PCBs	Training Safety inspections Work planning BNL Chemical Management System Committee review for changes Adherence to Suffolk County Article 12 Waste handling and control procedures Process evaluations P2 ISO 14001 management system
RADIATION Electron Beam Radiations Beam Losses through routine/fault operations Skyshine Activated Materials	Design calculations and reviews Shielding Access Controls Interlocks, chipmunks, crash buttons, and visual/audible alarms for beam imminent Fences and posting Beam fault studies Training Area Monitoring TLDs Follow BNL Radiation Control Manual and SBMS ALARA reviews RWPs and work planning
ELECTRICAL Normal electric shock hazards from electrical distribution service at 115 volts single phase Systems at the ATF that operate off 208 or 480 volts three phase The high pulse voltages up to 50 KV found in the modulators driving the klystron amplifiers which provide the radio frequency power to drive the linear accelerator There are no exposed electrical systems at voltages greater than 24V except for the 90° Magnet Power	BNL SBMS Design reviews Conductors covered Postings and barriers Fused circuits for experimental equipment Emergency off controls for power LOTO Training

Supply which is set to <50Vdc output	PPE for operating electrical equipment & for "working on or near energized conductors" Work Permits ESSH Committee reviews of changes Properly rated test equipment NRTL equipment or EEI inspections Safety inspections Work planning OHSAS 18001 management system
LASER A 2 mJoule per micropulse, up to 1500 micropulses pulses per second, 1 GW peak power, Nd:YAG laser (Class IV) used to excite the electron gun cathode. A pulsed, terawatt peak power CO_2 laser (Class IV) , which is used to accelerate electrons in specially designed accelerator devices housed in the Experimental Area. Light from the FEL experiments that may produce laser hazards from Class II - IV. Other lasers may be used in experiments and are reviewed in compliance with the relevant subject areas, i.e. Work Planning and Control for Experiments and Operations, and Laser Safety.	Interlocked Rooms Training Laser Safety Eyewear Enclosed Beam Paths Beam Stops Laser Tier I Inspections ATF Nd:YAG Laser Procedures ATF CO2 Laser Procedures LSO Approval of Procedures Safety inspections Work planning
NON-IONIZING RADIATION The klystrons which provide the radio frequency power for the accelerator utilize a permanent magnet (5 gauss @ 1.4 meters) for beam focusing and provide high radio frequency power at an operating frequency of 2856 MHz.	This power is transmitted from the klystrons to the accelerating sections and electron gun via vacuum waveguides IH Field Mapping
FIRE	Fire Hazard Analysis – September 2009 Automatic Fire Suppression Systems Fire Alarm Systems Automatic Detection Systems Fire Extinguishers Adherence to Life Safety Code Emergency lighting Training Safety inspections Work planning BNL Fire/Rescue Group response

Table 1: Hazards and Controls

3. SITE FACILITY AND OPERATIONS DESCRIPTION

3.1 Site Location

3.1.1 Introduction

The BNL Accelerator Test Facility (ATF) has been evaluated as mandated in DOE Order (420.2B) "Safety of Accelerator Facilities," against the criteria of DOE Order 6430.1A "General Design Criteria" regarding wind, flood, and earthquake design criteria. DOE Order 5480.28 "A Natural Phenomena Hazards Mitigation" (NPH) and its associated standards were used as guidance for this evaluation. Details on site geography, seismology, meteorology, hydrology and demography are contained in "DOE Accelerator Order (420.2B) Implementation Plan for Brookhaven National Laboratory Natural Phenomena Hazards Evaluation" April 25, 1994 by Steve Hoey. It is the consensus of seismologists that no significant quakes are to be expected in the foreseeable future. The ATF Building is a pre-existing structure built in the early 1950's, operational in 1957.

An Accelerator Readiness Review (ARR) was performed prior to the operation of the Accelerator Test Facility in 1989.

3.1.2 Accelerator Test Facility Location

The ATF is a user facility for accelerator and beam physics. It is operated by the Physics Department and the Center of Accelerator Physics (CAP) to study advanced acceleration techniques and to carry out research involving free electron lasers and basic electrodynamics. This facility makes use of a 120 MeV electron linear accelerator utilizing a radio frequency electron gun excited by a semiconductor laser giving very short photon microbunches to provide a very bright source of electrons with total charge of 1 nanocoulomb per microbunch. The ATF is under the administrative control of the Physics Department. The ATF is housed in the west side of Building 820 consisting of a steel exterior and frame, housing a single story with a high-bay area. Building 820 is bounded by Renaissance Road to the west and Rutherford Drive to the north.

3.2. Accelerator Systems Design

3.2.1 Introduction

The linear accelerator (Figures 1 and 2) comprises an electron gun, a low energy beam transport system, two traveling wave accelerator sections and a high energy beam transport and beam shaping system. The klystron amplifiers and cooling systems are situated in the low bay area adjacent to the accelerator components, while the klystron modulator and other power supplies and controls for the beam transport and beam monitoring equipment are situated on a mezzanine above the accelerator. The accelerator and transport system is enclosed in a combination of lead and concrete, or borated polyethylene shielding of sufficient thickness to allow normal occupancy of the adjacent areas of Building 820. Shielded beam stops are provided for both electron gun and total Linac operation in the accelerator tunnel in Building 820. The fenced off area next to the electron gun, the experimental hall, the CO_2 laser room (C1, C2) and the optical diagnostic room (C3) are radiologically Controlled Areas but not Radiation Areas.

3.2.2 Design Criteria

All of the accelerator and beam line components have been designed to conform to applicable guides, codes and standards at the time the ATF was constructed and became operational in 1989. There are no deviations from DOE current design criteria. Any non-commercial equipment supplied

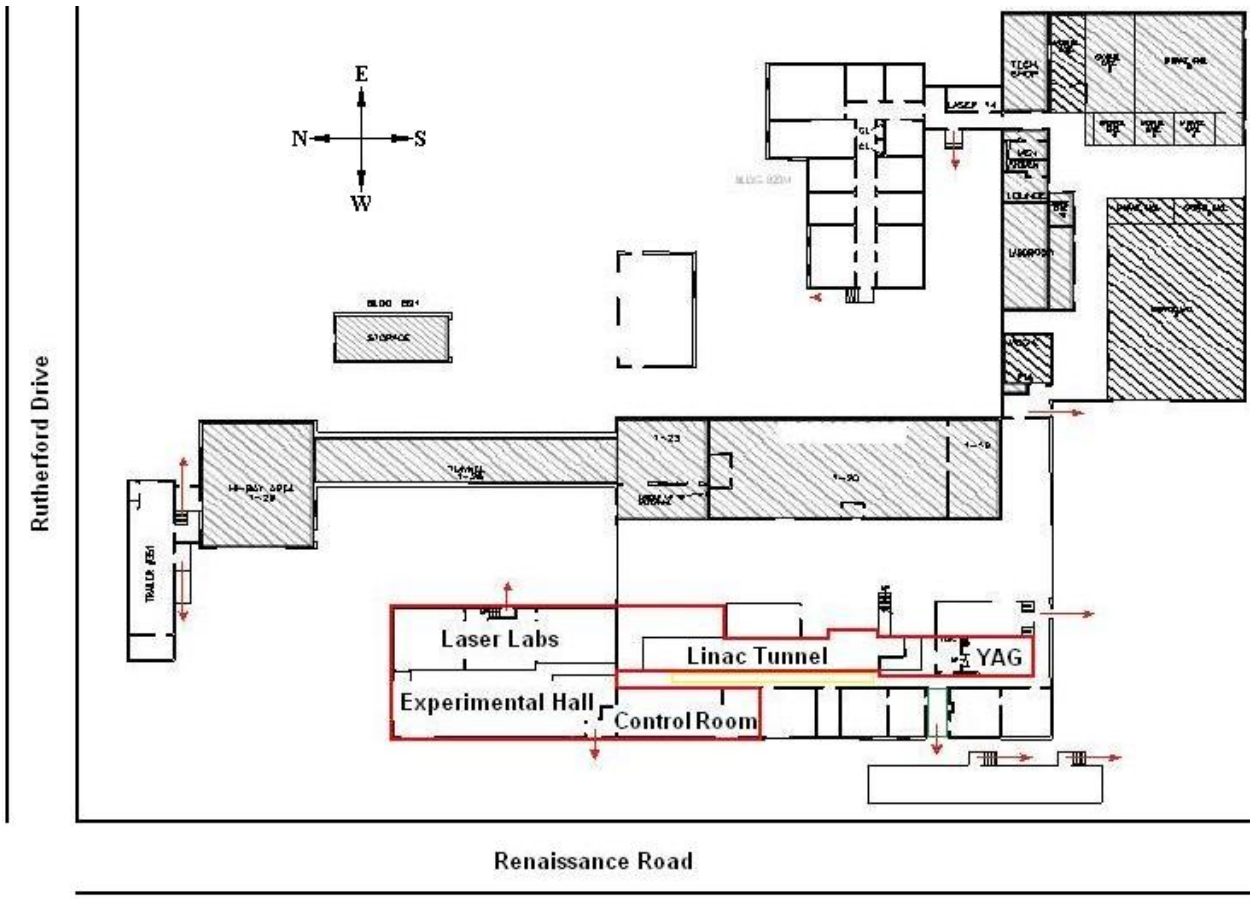

Figure 2: Outline of the ATF subject to the SAD within Building 820. Figures 1a and 1b show the South and North portions of the area, respectively.

to the ATF is reviewed by the ATF chief electrical or mechanical engineer and the Physics Department's ESSH Committee as appropriate. The evaluation criteria are given in the ATF Handbook. A separate safety review of the Accelerator Test Facility mezzanine and jib crane has been carried out and is available in the Physics Department's Safety & Training Office.

The ATF Handbook gives guidelines to be used in the design of electrical equipment, which are within those given in BNL's SBMS *Electrical Safety* Subject Area that conforms to applicable DOE standards.

The interlock system design and search procedures are given in the Procedures for the Accelerator Test Facility. These systems are reviewed by Physics Department and BNL committees prior to their implementation and are in compliance with BNL's SBMS *Electrical Safety* Subject Area.

Experimental Reviews are carried out by the Physics Department Experiment Review Coordinator and the ESSH Committee and are in compliance with the Subject Area, *Work Planning and Control for Experiments and Operations*.

3.3 Fire Hazard Analysis

3.3.1 Introduction

The purpose of this section is to evaluate the ATF fire protection in regard to compliance with DOE Order 420.1. A detailed "Life Safety Code Analysis" is contained in Appendix I and a *Fire*

Hazard Analysis Building 820 Accelerator Test Facility (ATF), September, 2009 is on file in the Physics Department's Safety and Training Office.

3.3.2 Summary

The Accelerator Test Facility is housed in the low bay area of Building 820 and in an experimental building attached to the north end of 820 (see Figures 1 and 2).

New building additions added for ATF use have been provided with smoke detection and sprinklers. A sprinkler main has been brought into the building from the street and automatic sprinkler protection is provided in the experimental building. The mezzanine which houses much of the ATF electrical equipment is located in the low bay area of Building 820 and it has been provided with automatic sprinkler protection.

The FHA completed in September 2009 was done for the entire building and has recommendations for work to be done in the building. The ATF utilizes only a portion of the building and the relevant findings/recommendations are given below.

The building is not provided with lightning protection,

The building is not fully protected with automatic sprinklers,

The Gun Hutch in the YAG Laser Lab is not protected with smoke protection,

Trees are within 30 feet of the modular Building 355, and

The heat detection system in building 820B (storage building) should be raised to be within 20 inches of the ceiling.

The recommendation for sprinkler protection within the ATF has been incorporated into the BNL Strategic Fire Safety Plan (SFSP). The SFSP incorporates all the fire safety deficiencies faced by BNL and addresses these in a prioritized fashion. Installation of all of these recommendations in Building 820 will be tracked by the Physics Department to completion.

3.3.3 Analysis

The overall occupancy classification of the ATF area of Building 820 for Life Safety Code (LSC) purpose is General Industrial. No high hazard operations are associated with the operation of the ATF in Building 820. The occupancy load is above 100 sq. ft./person and the doors provide adequate means of egress. Stairs comply with the requirements of NFPA 101 and egress paths are of the required width. Common paths of travel and dead-end corridors are within the maximum allowed. Travel distances to exits are also in compliance with LSC and all exits discharge directly to a public way.

Adequate emergency lighting is provided and the required means of egress are adequately marked.

The ATF area of Building 820 is protected with a combination of automatic sprinklers, fixed temperature/rate of rise heat detectors, smoke detectors and manual fire alarms. Alarms are arranged to annunciate; locally, at BNL Fire/Rescue Headquarters (Building 599), and at BNL Police Headquarters (Building 50)

3.4 Safety Organization

3.4.1 Introduction

From a management viewpoint, safety is represented at a high level at the ATF. One can see from the ATF organization chart (Figures 3a & 3b) that the ATF Head has direct line responsibility

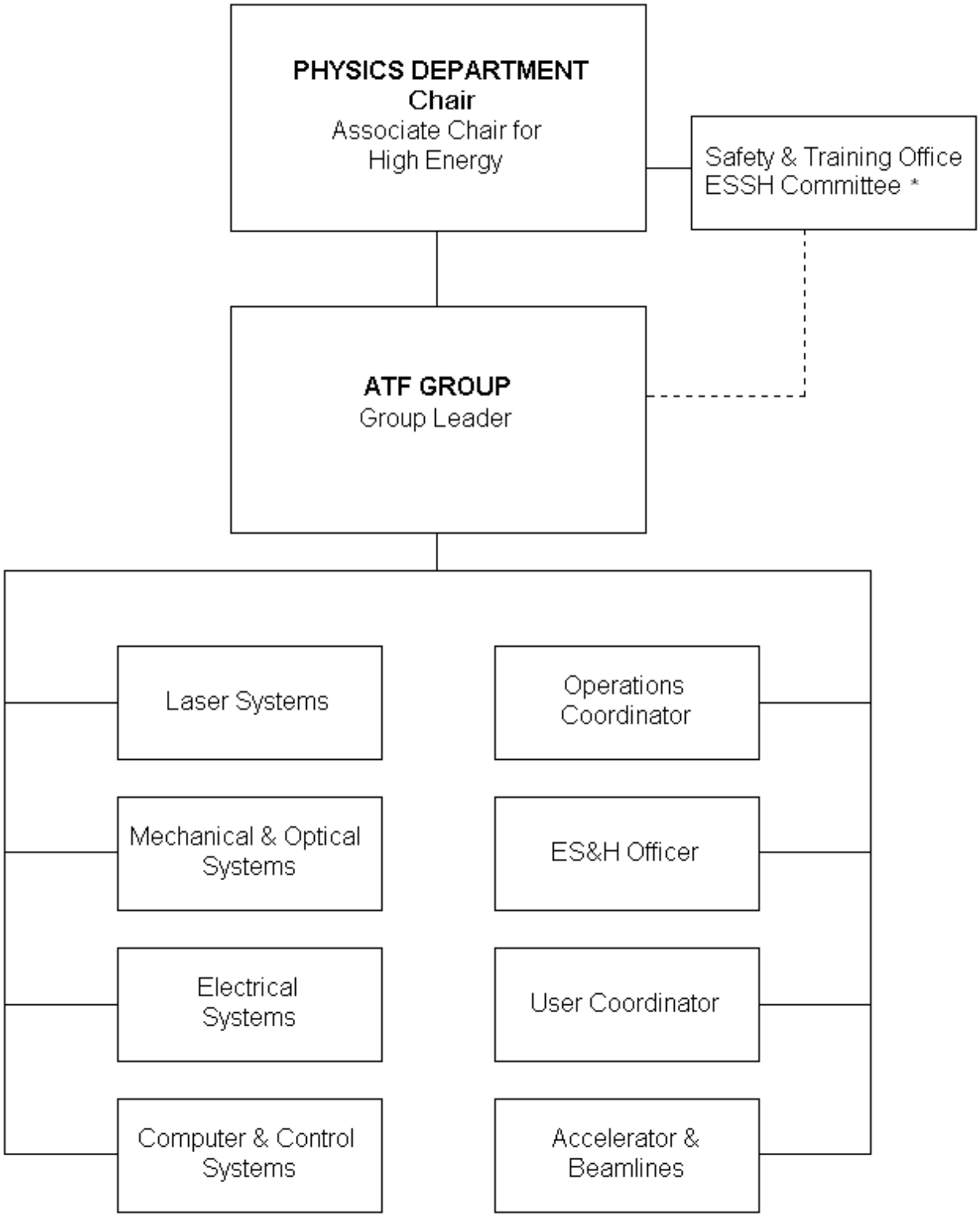

Figure 3a: ATF Organization Chart
*Includes representatives from the DOE, Radiological Control, Industrial Hygiene, and other SMEs as applicable.

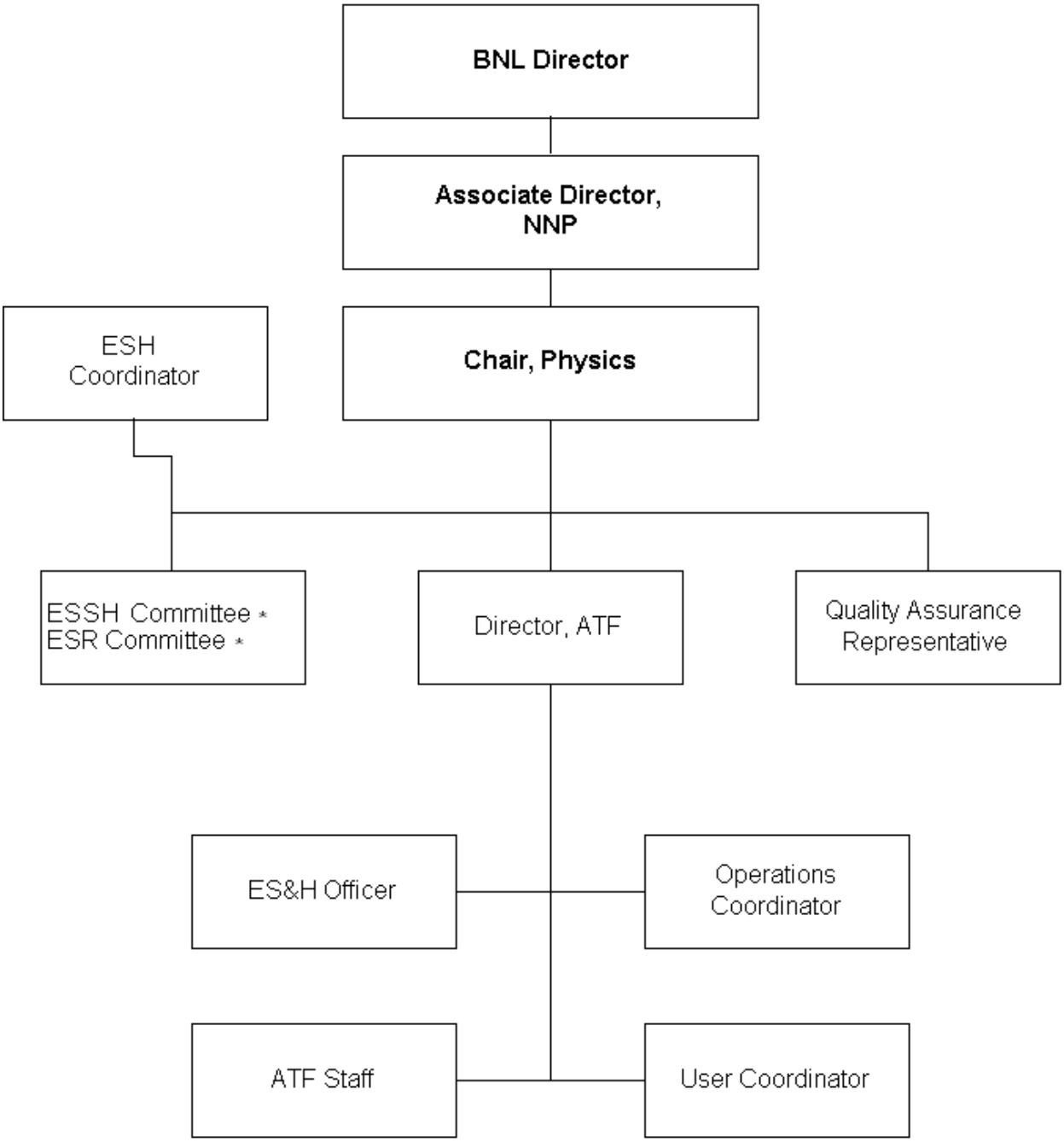

Figure 3b: Safety Organization Chart, Accelerator Test Facility
*Includes representatives from the DOE, Radiological Control, Industrial Hygiene, the ECR, and other SMEs as applicable.

for the ATF Safety Program, which is administered through the Physics Department. The existing Physics Department Environment, Safety, Security, and Health Program serves as the umbrella for the ATF Safety Program. An Emergency Plan has been developed for the ATF together with training programs. The ATF operation and experimental programs are included in the Physics Department's

ISO 14001 Environmental Management System.

3.4.2 Safety Committees

The ATF program is administratively part of the Physics Department and as such is reviewed by the Physics Department's Environment, Safety, Security, and Health (ESSH) Committee for the operation of the accelerator and the experimental facilities. The Physics ESSH Committee consists of Physics ESSH and professional staff as well as the DOE Brookhaven Area Office Facility Representative, the Environmental Compliance Representative, Industrial Hygiene Representative, and Radiation Control Facility Support. Other SMEs are included as needed or required. Guidelines for the Physics ESSH Committee are listed in Physics Department's *ESH&T Policy Responsibilities and Authorities*.

All hazards and controls that are not described in the SAD, in accordance with the SBMS Subject Area, *Work Planning and Control for Experiments and Operations*, are reviewed and authorized by Work Permits (WPs) or Experimental Safety Reviews (ESRs). WPs for work that is not Low Risk and Complexity require additional reviews and approvals.

All experiments (or modifications to experiments) are reviewed and approved by the Physics Department's ESSH Committee, which functions as the Experimental Safety Review Committee, bringing the same expertise as described in the above paragraph. In addition, each experiment (or modification of an experiment) may require a radiation survey carried out by a Radiological Control Division representative and ATF Operator as determined by the ESSH Committee. The survey includes fault conditions. If an experiment does not satisfy safe operating conditions at the complete perimeter of the Experiment Hall it is not allowed to run. This would invoke the USI process. Shielding calculations must be carried out, and appropriate shielding provided, to ensure that radiation levels outside of the shielded area are in compliance with BNL standards. Experimental reviews and approvals are in compliance with the BNL Subject Area, *Work Planning and Control for Experiments and Operations*. Finally, SMEs and laboratory level committees are consulted when required or for hazards for which the ESSH Committee needs additional review or approval.

3.4.3 Laboratory Environment Safety and Health Committee

Whenever policy changes not covered by this document or requiring a new SAD are made by the Physics ESSH Committee they are brought to the Laboratory Environmental, Safety and Health Committee for their review and recommendation for approval by the Director's Office. The policies are not implemented until such a review has taken place and approval has been obtained. In addition to the BNL ES&H Committee Reviews, members of the ESH Directorate act as advisors to the Department in any safety matters. The Physics Department's Safety and Training Office assists in the implementation of the Laboratory Safety Program and also assists in training Physics/ATF personnel in safety matters.

Accelerator Readiness Reviews are conducted by a committee appointed by the Deputy Director of Operations prior to operation of the Facility or when there is a major change in equipment layout or operations, which require a further review of this and other documentation.

3.4.4 Safety Training

For most of the training areas, the Laboratory provides web-based or classroom training. However, there are a number of topics related to the Accelerator Test Facility, which require separate training programs. ATF Training Programs and Requirements are given in the ATF Handbook, a

controlled document. In addition to the training required of all employees, users of the facility are required to take a variety of training dependent on the work they will be performing and receive an ATF site specific training. This training is tracked through the BTMS, the Brookhaven Training Management System.

3.5. Experimental Operations

3.5.1 Introduction

The experimental area is divided into two separate regions, the fully interlocked laser rooms and the radiologically controlled experimental hall within them. The arrangement is shown in Figure 1b. Detailed layout and shielding studies have been made, as described in Section 4.5.2, and originally reviewed by the NSLS, subsequently by the Physics Department, and BNL's ES&H Committee. The radiologically controlled experimental hall can be entered via a dual interlocked door at the southwest corner of the experimental area or by the dual interlocked door from the FEL experiment room. A double entry door is provided for heavy equipment access to the experimental area and this is situated on the west side of the experimental area near the north end of the building. This door has dual interlocks so it is only available for equipment installation during maintenance periods. Three or more separate experiments may be set up in the experimental area, though only one can operate at any given time. The experimental area is a secured and interlocked radiation area not occupied during beam operation.

The high power lasers used for experimental research are housed, and transported between, the interlocked laser areas that are under controlled access as described in Section 4.5.3.2 of this report and in the Procedures for the Accelerator Test Facility. There are SOPs for the lasers which are reviewed and updated annually and subject to the Laser Tier I Inspections performed by BNL's Laser Safety Officer. These areas are shielded from the experimental beam lines so that they may be occupied while the linear accelerator and experimental program are in full operational modes. There are three entry points to the laser areas, one through the door located on the east side, through a vestibule, one through the south door to the High Bay, and one through the north door of the experimental hall. The dual interlocked personnel access door between the experimental hall and the FEL room is also used as an emergency exit from the FEL room. There are four independent laser rooms. They house the CO_2 lasers and the terawatt amplifier, both of which provide optical radiation for acceleration of electrons in experiments set up in the experimental area, and include the FEL experimental room which is used to analyze the light produced by the various FEL experiments, and the experimental hall itself. The experimental hall is a laser-controlled area that may be secured for laser and/or radiation. The FEL experiments may produce laser hazards from Class II – Class IV, while the facility lasers are strictly Class IV. Laser interlocks for the experimental hall are a separate and independent system except for the shared laser & radiation emergency stop buttons.

3.5.2 Experimental Area Operation Modes

Experiments are set up in one of the three beam lines shown in Figure 1b. The beam line which first bends to the right after entering the experimental area is a relatively low current beam line operating at less than 10^8 electrons per second and ordinarily poses a relatively low radiation hazard. The other two beam lines are utilized for high current experiments ($\geq 10^{10}$ electrons/second) and therefore pose more serious radiation hazards. However some experiments carried out on this beam line require a momentum analysis system that may require bending the beam towards the exit door labyrinth. This can give rise to gamma rays being produced by off energy electrons striking the beam

pipe upstream of the shielded beam stop.

3.5.3 Radiation Hazards

In 4.5.2 we have estimated that 5 x 10^{19} electron MeV per month will be delivered to the beam stops situated at the north end of the experimental area. This will give rise to substantial bremsstrahlung radiation from electrons stopped in the beam stops and photoneutrons requiring concrete shielding. Fault conditions cause the electrons to be lost at other places in the beam transport lines, particularly where bending occurs, so it is necessary to shield the beam lines as well as the beam stops in the experimental area. Lead collars situated at intervals along the beam line are also used. The beam line area is enclosed in concrete and the beam line is shielded by at least a 1.5 foot equivalent or greater, as shown in figures 4 & 5.

ATF Staff wear TLDs at all times while in Controlled Areas. Offices, laboratory and industrial areas where much of the work is done in preparation for experimental runs are done outside the Controlled Areas. During experimental setup, the electron beam is not present in the Experimental Hall. All these precautions have led to a zero accumulated dose for the workers and users as recorded on their TLDs. Furthermore, Facilities and Operations personnel, including the custodial staff, receive no exposure at the ATF.

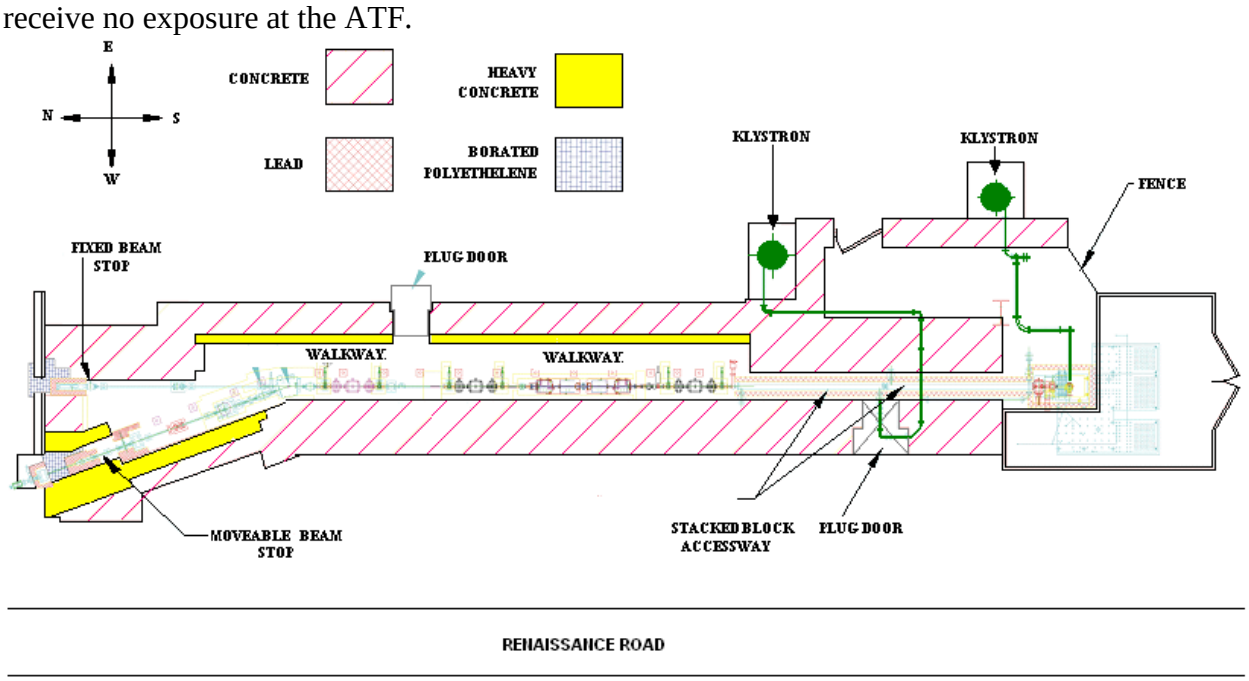

Figure 4: ATF, Building 820 Shielding

During early beam tests and commissioning, area radiation monitors were provided near each operating beam line to monitor fault conditions. Remote readout radiation monitors are located at sites where accidental beam losses may occur and machine operators are trained and have written instructions on the actions required if unusual radiation levels are experienced and alarms are sounded. Area monitors have been placed where dose levels are greatest and where verification of dose is needed. These monitors have been recording dose since 1995 as shown in Figure 6 and Table 2. Figure 1b shows the typical plan layout of shielding in the Experimental Area. Section 4.5.2.2 gives details of the shielding provided for this area.

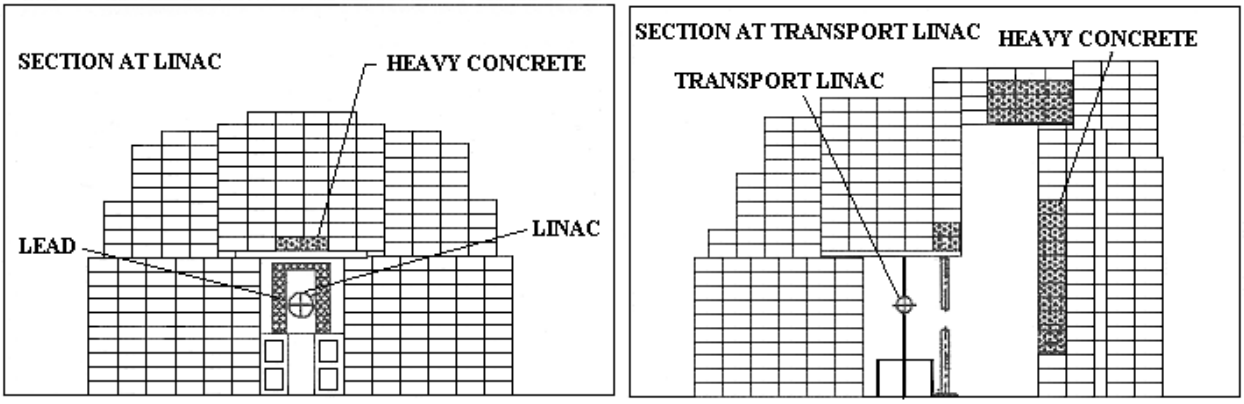

Figure 5: ATF Building 820 Shielding at the Linac and Transport Linac

	TLD 72	TLD 72	TLD 73	TLD 73	TLD 74	TLD 74	TLD 75	TLD 75	TLD 76	TLD 76
	Neutron	Gamma	Neutron	Gamma	Neutron	Gamma	Neutron	Gamma	Neutron	Gamma
1995	13	40	3	4	26	212	7	0	11	3
1996	14	122	4	1	8	148	6	0	8	2
1997	5	18	3	0	7	89	3	2	4	7
1998	5	110	1	0	7	3	3	0	3	0
1999	94	43	9	34	7	1	1	9	3	4
2000	11	54	3	0	11	6	4	0	3	0
2001	26	68	3	0	3	9	0	0	2	0
2002	3	8	0	0	0	2	0	0	0	0
2003	9	94	1	51	0	68	2	33	5	51
2004	9	87	3	50	1	65	1	43	3	45
2005	2	90	1	50	2	60	1	38	2	41
2006	7	87	2	49	0	63	1	38	0	42
2007	8	81	1	51	0	62	2	39	1	42
2008	2	22	1	12	0	14	0	10	1	15
	TLD 77	TLD 77	TLD 78	TLD 78	TLD 79	TLD 79	TLD 80	TLD 80	TLD 81	TLD 81
	Neutron	Gamma	Neutron	Gamma	Neutron	Gamma	Neutron	Gamma	Neutron	Gamma
1995	6	0	12	7	12	5	160	37	5	2
1996	1	1	5	5	9	0	145	38	5	0
1997	1	7	3	11	6	0	206	35	3	0
1998	2	1	2	0	3	0	29	4	2	0
1999	3	7	3	7	19	4	17	14	10	8
2000	3	14	4	2	4	3	60	7	3	0
2001	2	0	4	0	3	0	84	2	4	0
2002	0	0	0	0	0	0	23	0	1	0
2003	6	49	7	52	6	57	80	49	26	50
2004	2	50	5	48	2	52	45	53	5	46
2005	0	45	4	47	2	48	24	45	3	38
2006	0	44	3	49	3	48	23	41	1	34
2007	2	43	2	44	3	48	41	51	2	41
2008	0	10	1	13	1	13	10	13	0	11

Table 2: ATF TLD Totals for the Years 1995 – 2008 (in mRem)

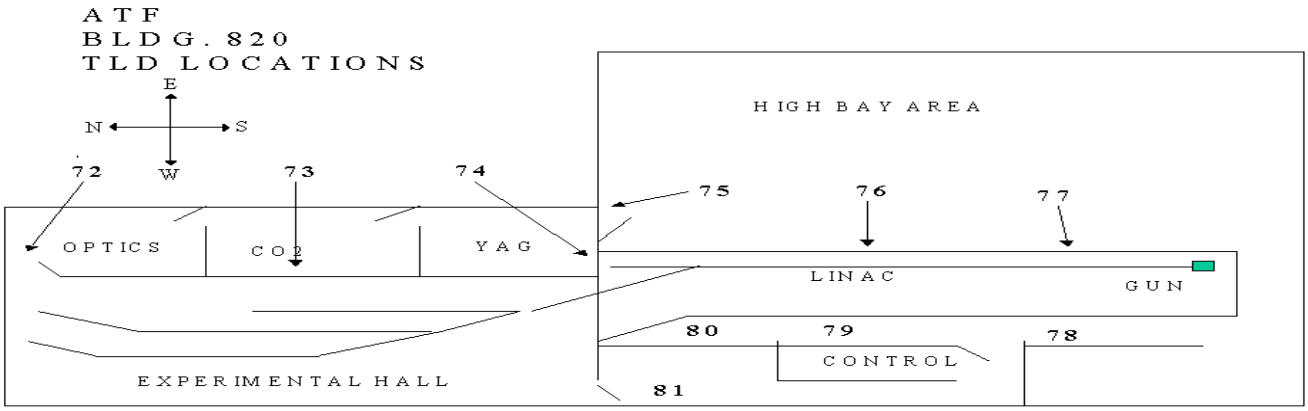

Figure 6: Locations of Area Monitors

3.5.4 Electrical Safety

The electrical distribution systems for the Experimental Area and the Laser Equipment Room are similar to that described in Section 3.6.4 and conform to the same codes and conditions. Door interlocks and grounding sticks are provided as necessary.

3.6 Operations Process

3.6.1 Introduction

	Hardware Limited Maximum	Original Design Maximum
Output Beam Energy	85 MeV	120 MeV
Pulse Repetition Frequency	1.5 Hz	6 Hz
Radio-frequency Pulse Length	3.5 μs	3.5μs
Beam Pulse length (nominal)	10 ps	10 ps
Beam charge in one pulse	0.5 nC	* 1 nC
No. of beam pulses / macropulse	1 to 10	100

Table 3: ATF Summary Table of Operating Parameters

* The maximum charge of 1nC may not be practical for 100 bunch operation since it will, in general, cause beam loading in the electron gun that would change the beam energy and could cause the beam to be lost in the gun region and not be accelerated through the accelerating sections. In fact, for a charge of 1nC per beam bunch there could be a change in gun voltage of more than 6.5% during the duration of the 100 beam bunches and it is unlikely that this mode of operation at this level of charge would be useful for any of the planned experiments. At the present time the best operation, in multi-bunch mode has been with about 10 bunches with 0.5 nC or less per bunch.

Different experiments run at different energies. The original design limit of the hardware is 120 MeV for accelerating electrons. We operate up to 85 MeV, since higher energies exceed the limits of the current hardware. The maximum energy electron beam, 120 MeV, is what the shielding was designed to protect against.

The accelerator system has a number of different operating modes but for the purposes of this document we will concern ourselves with the mode giving rise to the most serious radiation hazard. In this mode the electron gun is operated in a multi-pulse laser mode and includes "dark current" electrons, where the beam pulse length is essentially equal to the radio frequency pulse length of up

to 3.5 μsec which is the maximum attainable from the hardware utilized in the modulator and klystron tank. Note that, due to the high radio frequency field gradients present in the electron gun, field emission occurs which gives rise to what are called "dark current" electrons. These are accelerated in all directions by the strong electric fields present in the gun and thus produce intense x-rays around the electron gun. If the accelerator sections are misphased with respect to the electron gun, or each other, most of the electrons accelerated from the cathode are lost at energies between 5 MeV and 120 MeV over the whole length of the Linac accelerator section and/or the beam transport system. It is also possible to mis-steer the 5 MeV input beam so that essentially a point source at the 5 MeV energy impacts the collimator just before the entrance to the first accelerating section. The radiofrequency gun will accelerate these "dark current" electrons to ≈5 MeV for essentially 180° of each RF cycle and will operate at up to a maximum attainable rate of 6 pulses per second. This can, under some operating conditions, give up to 10^{12} electrons per second from the gun at an energy of 5 MeV and an energy spread of up to 500 KeV. A large number, of the order 90%, of these "dark current" electrons will be lost in the transport system situated just upstream of the accelerating sections. Others will be lost due to the RF capture process so only 10^{11} electrons per second will be available for acceleration through the two nominally 50 MeV accelerating sections. During low energy operation the electron gun is operated on its own with the beam being stopped in the collimator, which can also be used as a beam stop. A maximum power of 10 MW is available for gun operation. At this maximum power level output energy of up to 7 MeV is possible, assuming that the gun cavity is able to withstand the voltage obtained at this power level. The gun shielding and slit shielding are designed for this eventuality.

When the gun is operated with a photocathode, the beam microstructure is better defined and in this mode of operation the beam losses are lower by one to two orders of magnitude over the above situation. However, with the maximum available 100 microbunches each with a charge of 1 nC, there would be 6 x 10^{11} electrons per macropulse or a total of 3.6 x 10^{12} electrons per second for operation at the maximum available repetition rate of 6 Hz. These photoelectrons can also be stopped at the low energy collimator so we have conservatively designed the shielding there for 10^{13} electrons per second at a maximum energy of 7 MeV.

The high-energy beam will be utilized for experiments carried out in one of the three available beam lines in the Experimental Area. The beam will be stopped after the Experimental Region in one of the fully shielded beam stops located at the end of the beam line in use. For tune up purposes and testing of accelerator components such as beam diagnostic equipment the beam may be stopped in a beam stop at the end of the straight ahead line housed in the shielded area of the Linac (see Figure 4). This is provided with the equivalent lead and concrete (and/or borated polyethylene) shielding as the beam stops at the end of the beam lines in the experimental area. A second fully shielded beam stop, after a bending magnet and defining slit in the line directed towards the Experimental Area, is used for tune-up purposes. It is possible to set up equipment in the Experimental Area and Experimental Laser Area while operating for tuning and testing.

3.6.2 Controlled Entry to the Experimental Hall

Entry to the experimental area hall is via two doors, one at the south and one through the laser areas FEL room at the north end of Building 820. Radiation protection interlocks are provided so that a doubly interlocked electron beam stop, situated in Building 820 in the transport line, near the junction of the linac tunnel Building 820 and the experimental building, is secured in place before entry to the shielded region of the experimental area is allowed. The experimental laser area is

separately interlocked and shielded from the experimental beam lines with a door from it to the experimental area having the same interlock provisions as the other door to this area. A double door, situated at the northwest corner of the experimental building that is normally for egress only during non-beam operation allows forklift access to the experimental building for the delivery of large equipment. This door is also dual electrically interlocked. A movable shielded plug door provided for neutron shielding made up of borated polyethylene blocks and situated inside the double entry doors is moved into position and secured in place before a search of the area and operations can commence. Securing this plug door is included in the search and secure procedure given in Section 4.5.3.1.2 of this document and is also described in the Procedure for Operation of the ATF.

The ATF laser equipment area security interlock system, which allows controlled entry into the laser area rooms, while both the electron and Class IIIb or IV laser beams are in operation, is described in Section 4.5.3.2 of this document.

There are no special requirements with regard to general building entry since all radiation areas and laser operation areas are separately controlled.

3.6.3 Fire Hazard and Control

Building 820 is one of the older buildings on the BNL site; as such it does not contain a full building sprinkler system. Smoke and heat detectors are provided and there is an annunciator and signal system tied to the Site fire alarm system. Portable fire extinguishers are located throughout the ATF. The maximum travel distance to a fire extinguisher is 75 feet. Individual laboratories have their own fire extinguishers and smoke detection equipment.

The trailer, experimental area (experimental hall, CO_2 laser rooms, FEL optical room - see Figure 1b) and the equipment mezzanine in Building 820 are provided with automatic sprinkler protection. Smoke detection is provided in the experimental area, the mezzanine, the Control Room, the offices, the machine room and the YAG laser area. All other areas of the ATF are provided with heat detectors. Exiting for fire emergencies complies with the Life Safety Code NFPA101, 1994 (see Section 3.3 of this SAD).

The total value of the equipment located in the control room will not exceed $300,000.00 and all of it could be replaced within a six-month period. Backup magnetic tapes for the main operating system are stored in a metal file cabinet in another area of the building so the programmatic loss due to a fire would be minimal. Most of the high cost equipment in the ATF is directly associated with the accelerator itself, is made from copper, and is under a lead and concrete shield where it is protected from an external fire. The power equipment such as the pulse forming networks/modulators and power supplies for bending magnets, etc. are situated on the sprinklered mezzanine above the accelerators. The major cost items are the modulators and power supplies for the klystrons each of which cost $200,000.00. The two klystron amplifiers required for final operation were obtained from SLAC for shipping cost only. There is also approximately $275,000 of CAMAC equipment on the mezzanine. The CAMAC equipment could be replaced within six months.

Spares for the main components of these systems are available so they could be reconstructed over a 3 to 6 month period depending on the severity of any fire damage.

3.6.4 Electrical Safety Issues

The electrical power to operate the accelerator is distributed to the equipment at 208 or 480 volts, three phase, or 115 volts single phase, each with a separate ground connection. The installation

of the distribution equipment is according to standard industrial practice for equipment of this type and conforms to applicable ANSI National Safety Codes and the National Electric Code. In order to prevent the electric shock hazard all control and instrumentation systems are well insulated, and operate at voltages less than 24 volts rms, the exception being the 90° Magnet Power Supply which is set to <50Vdc output. They are within guidelines set forth in ANSI Spec. #39.5 (Electrical and Electrical Measuring and Controlling Instrument Safety Requirements) and DOE/EV-0051/1 (Electrical Safety Criteria for Research and Development Activities). Voltages above this 24 volt rms level for both AC power distribution as well as DC and AC equipment are either lock or interlock protected or behind bolted panels and covers according to the serviceability of the equipment. The klystron pulse forming network/modulator system enclosures, which house high voltage equipment, have their entry doors electrically interlocked so that the high voltage is turned off when any of their doors are opened. In addition, grounding sticks are provided outside these enclosures to manually ground high voltage points within the enclosures prior to working on these systems. Unauthorized entry into the experimental hall will cause the Linac modulator to be turned off via a dual electrical interlock with this door and will cause a beam stop to be inserted in the high energy beam transport line. All the main circuit breakers for the power distribution system have lock out capability. The ATF Electrical Standards are given in Section 2.04 of the ATF Handbook.

3.6.5 Occupational Health Hazards and Controls

3.6.5.1 Non-Ionizing Radiation

The klystrons which provide the radio frequency power for the accelerator utilize a permanent magnet (5 gauss @ 1.4 meters) for beam focusing and provide high radio frequency power at an operating frequency of 2856 MHz. This power is transmitted from the klystrons to the accelerating sections and electron gun via vacuum waveguide.

3.6.5.2 Laser Issues

High power lasers (Class IV) are utilized to irradiate the cathode of the radio frequency electron gun and to accelerate electrons in the Experimental Hall. The laser beams are transported between rooms in enclosed pipes or inside interlocked enclosures for personnel protection. The laser systems are covered in the laser SOPs which enumerates the hazards and controls.

3.6.5.3 Compressed Gases

Compressed gases are used in the facility primarily in support of experiments, although some are used for operations, for example CO_2 in the laser. Experimental gas use is evaluated in the ESRs for experiments. All compressd gas use complies with the relevant Subject Area(s).

3.6.5.4 Cryogen Use and ODH Evaluation

Cryogens are used to cool detectors and superconducting magnets at the facility. These are part of user experiment and are evaluated in the ESR associated with each experiment. ODH evaluations are made using guidance from the Subject Area and in consultation with the SME.

3.7 Worker Safety Controls

3.7.1 Introduction

Facility hazards have been analyzed and mitigated as prescribed in the SBMS and presented in this SAD. No activity or facility modification may compromise the SAD or the ASE. Proposed

changes are to be screened for hazards that lie outside the bounds of those considered in the SAD and in the development of the ASE. This is accomplished by implementing the Unreviewed Safety Issue (USI) Process, as described in the SBMS Subject Area, *Accelerator Safety*. This process follows from DOE O 420.2B Contractor Requirements Document and DOE G 420.2-1, Accelerator Facility Safety Implementation Guide for DOE O 420.2B. The USI process may result in rewriting portions of the SAD and modifying the ASE. Such revisions require applicable review and approval. Reportable events may also cause the USI process to be initiated.

All hazards and controls that associated with routine work or experiments, not described in the SAD, in accordance with the SBMS Subject Area, *Work Planning and Control for Experiments and Operations*, are reviewed and authorized by Work Permits (WPs) or Experimental Safety Reviews (ESRs). WPs for work that is not Low Risk and Complexity require additional reviews and approvals. Any changes that may compromise the SAD or ASE undergo the USI Process.

3.7.2 Occupational Health Controls

Worker safety controls used at the Accelerator Test Facility include "fully" interlocked and controlled enclosures for radiation, laser and electrical safety as well as radiation monitoring and protective equipment.

Everyone working at the ATF in these areas is provided with a personal dosimeter that is collected and read monthly. In addition Area TLD's are located at appropriate locations around the facility, outside the shielded area. These are read and recorded on a regular basis and a database is maintained. Also a number of "CHIPMUNK" radiation monitors are used where accidental or unusual operations conditions could give rise to some radiation. They are read out and alarmed locally and in the Control Room but do not control the beam.

The klystrons, which utilize permanent magnets developing fields of the order of 5 gauss at 1.4 meters, are situated in an elevated location not normally accessible to workers or the general public. Experiments may also make use of permanent magnets, as do the ion pumps for the beam lines. Warning signs are posted in the area of magnetic fields in compliance with the Static Magnetic Fields Subject Area and all workers in these areas receive Static Magnetic Field Training.

Safety goggles are provided for those workers who need to enter the interlocked laser areas in order to make adjustments while the lasers are operating. Eye examinations are required and only trained and authorized personnel may work in the laser areas.

7 Guiding Principles of Integrated Safety Management and How the ATF Implements Them	
Line Management Responsibility for ESSH	Responsibilities are well documented (Physics Department Policies, SBMS, etc.) Weekly Engineering & Friday Afternoon Meetings with discussions of safety Group Leader involvement in any incident/accident investigation Department Management and Group Leader participation in Tier I Inspection Department Line Management participation in Safety Observations Department Chair directs Group Leaders to appoint a Group Safety Coordinator, and Group Leaders allow that person to spend time on ESSH issues
Clear Roles and Responsibilities	All employees have R2A2s Safety Responsibilities well defined by Department/ATF Policies

	JTAs reviewed annually or as jobs change
Competence Commensurate with Responsibilities	Authorized Worker Lists Users receive hands-on training (where applicable) Workers/Users are required to read and sign ESR or Work Permit
Balanced Priorities: on the grand scale, are the hazards being appropriately addressed?	The ATF addresses the hazards associated with work and recognizes its need to allocate resources to address safety, through its programs and operations. Job Risk Assessments are used to evaluate hazards or risks
Identification of ESH Standards and Requirements	The ATF follows the SBMS for all the standards and requirements it operates under
Hazard Controls Tailored to Work Being Performed	The ATF has comprehensive SOPs and ESRs that list and describe all the hazards and provide controls for each. This is a dynamic system that changes with feedback or as experiments evolve.
Operations Authorization	Comprehensive Check-in procedures and forms Systems training is an individual training providing an excellent platform for interaction and evaluation of competence. Authorized User Lists (Electrical Workers, LO/TO, Laser Operators, ATF Linac Operators, Modulator Operators, Machine Shops, Material Handlers) ATF Specific training SAD, ASE, COO, ATF Procedures

Table 4: 7 Guiding Principles of Integrated Safety Management

3.8 Environmental Aspects and Controls

The environmental aspects and impacts of the operation of the linac and its associated experiments is included in the Physics Department EMS. With our ECR we have done a process evaluation and are ISO 14001 registered. These are identified and evaluated at least annually by the Environmental Compliance Representative and summarized in a process assessment form. In addition, the ESR for each experiment includes identification of significant environmental aspects and establishes appropriate controls for those aspects.

The Klystrons at the ATF contain oil that is known to contain PCBs that can be in excess of regulatory limits. Anytime the oil is changed or discarded, it is analyzed to determine the PCB content and disposed of accordingly.

A transformer oil tank is registered as an Article 12 tank with the county. It is inspected periodically, in compliance with local regulations.

4. SAFETY ANALYSIS

4.1 Radiation Safety Hazards

4.1.1 Prompt Radiation Hazards

Both the electron gun, when operated at its maximum energy, and the linear accelerator, are producers of significant bremsstrahlung radiation. In addition, the "dark current" electrons also produce copious numbers of X-rays. Losses occur due to electron capture and/or equipment malfunction or missetting. The linear accelerator also gives rise to neutrons. Thus, we require both

lead and concrete or borated polyethylene shielding to protect personnel from the radiation hazard. Actual dose from 1995 through 2008, as recorded on the area monitors (locations shown in Figure 6), are shown in Table 2. These monitors give the total accumulated dose for each location for a full year constant occupancy. Other than the Control Room, there is virtually no occupancy at all other locations during operations. Control Room occupancy is limited due to the operations schedule (less than 40 weeks per year and less than 12 hours per day), and the number of operators. Results from Personnel Monitoring show no accumulated dose for all staff and users on an annual basis.

Normal electron losses will occur in the following locations and at the maximum energy and charge levels given below, for two modes of operation, i.e. for gun operation only and for full Linac operation.

Hazards	Controls
RADIATION	
Electron Beam Radiations	Design calculations and reviews
Beam Losses through routine/fault operations	Shielding
Skyshine	Access Controls
Activated Materials	Interlocks, chipmunks, crash buttons, and visual/audible alarms for beam imminent
	Fences and posting
	Beam fault studies
	Training
	Area Monitoring
	TLDs
	Follow BNL Radiation Control Manual and SBMS
	ALARA reviews
	RWPs and work planning

Table 5: Radiation Hazards and Controls

4.1.1.1 Operating Electron Gun Only

Under certain operating conditions of the electron gun**,** up to 100 μA of peak current electrons are produced as "dark current" by field emission from all surfaces of the electron gun where high electric field gradients are present. Some fraction of these electrons are accelerated axially, in the forward direction up to the maximum energy of the electron gun (~ 7 MeV) for a fraction of each rf cycle during the 3 μsec rf pulse. They are also accelerated in the reverse direction, to lower than maximum energy (~ 3 MeV) during the reverse part of each rf cycle. These "dark current" electrons produce copious amounts of X-rays around the electron gun region and require lead shielding.

In addition, at 100 microbunch operation at 1nC per microbunch from a photocathode including "dark current" electrons, potential losses occur at the following locations:

1. At a collimator/faraday cup situated before the linear accelerator sections, $\approx 3.6 \times 10^{12}$

electrons per second of up to 7 MeV energy. This is essentially a point source.

2. Missetting of the transport line solenoid magnets or trim dipoles. This would give rise to a loss of beam over a line source downstream of the misset device which would result in an estimated electron loss of up to 2 x 10^{12} electrons per second over a length of ≈ 50 cm at an energy of up to 7 MeV.

4.1.1.2 Full Linac

Operation at up to 1 nanocoulomb per 100 microbunches in 6 macropulses per second can give rise to losses at the following locations.

1. The above potential loss modes are also included in this mode of operation.
2. During the capture process of electrons in the first accelerating section, electrons may be lost along the length of both accelerator sections and at the first bend magnet of the high energy beam transport system**;** 10^{12} electrons per second at energies between 7 MeV and 120 MeV.
3. In the high energy beam transport momentum selection system or after any mis-set focusing or bending magnet in this line, up to 10^{12} electrons per second of energies between 7 MeV and 120 MeV may be lost**.**
4. At profile monitors or beam stops in the transport line or experimental hall, 3.6 x 10^{12} electrons/sec at 120 MeV energy are stopped.
5. At the Linac beam stop.

Clearly the worst case conditions are at the low energy collimator or other point sources of loss in the low energy beam transport system, where 4.6×10^{12} electrons per second from both dark current and photo current electrons can be lost at an energy of 7 MeV, and in the high energy beam transport system where a point source loss of 10^{12} electrons per second of 120 MeV electrons are possible. All beam stops are provided with extra local shielding and therefore do not represent a worst case hazard.

4.1.1.3 Radiation Dose Rates from Gamma Radiation and Neutrons

The calculations for gamma radiation and neutrons are given in Appendix III. The analysis shows that the existing tunnel walls and roof, more than 1m thick, provide the necessary shielding for all anticipated operating conditions.

4.1.2 Activation Hazards

4.1.2.1 Air Activation

The accident case in Appendix IV shows that for ozone, we won't get above 0.005 ppm for 8 hours and this is well below the TLVs listed by the ACGIH."

4.1.2.2 Soil Activation

An evaluation of the potential for tritium and Na-22 production in soil was conducted which concluded that tritium and sodium-22 production in soil from operation of ATF beam line 1 does not require any additional engineering controls or monitoring. The analysis is given in Appendix VIII.

4.2 Electrical Hazards

In addition to the normal electric shock hazards present in the operation of electrical equipment

operating off the building electrical distribution service at 115 volts single phase, there are a number of systems at the ATF that operate off 208 or 480 volts three phase. All cabinets housing these voltages are either secured by bolts or screws that can only be accessed internally, interlocked or are appropriately isolated. The high pulse voltages up to 50 kV found in the modulators driving the klystron amplifiers which provide the radio frequency power to drive the linear accelerator are all contained in cabinets with interlocked doors and automatic grounding of the high voltage, both mechanically and electrically, when an entry door is opened. In addition grounding sticks are available to manually ground the high voltage points within the modular enclosure prior to working on the system.

All ATF controls and instrumentation systems are well insulated and operate at voltages less than 24V rms. Magnet Power Supplies have outputs of 20Vdc or less with the exception of the 90° Magnet P.S. which is under 50Vdc.

Warning signs indicating high voltage hazards are posted in compliance with the Electrical Safety Subject Area.

Hazards	Controls
ELECTRICAL Normal electric shock hazards from electrical distribution service at 115 volts single phase Systems at the ATF that operate off 208 or 480 volts three phase The high pulse voltages up to 50 kV found in the modulators driving the klystron amplifiers which provide the radio frequency power to drive the linear accelerator There are no exposed electrical systems at voltages greater than 24V except for the 90° Magnet Power Supply which is set to <50Vdc output	BNL SBMS Design reviews Conductors covered Postings and barriers Fused circuits for experimental equipment Emergency off controls for power LOTO Training PPE for operating electrical equipment & for "working on or near energized conductors" Work Permits ESSH Committee reviews of changes Properly rated test equipment NRTL equipment or EEI inspections Safety inspections Work planning OHSAS 18001 management system

Table 6: Electrical Hazards and Controls

4.3. Occupational Health Hazards

4.3.1 Non-Ionizing Radiation Hazard

The radio frequency system for the linear accelerator utilizes two 25 MW peak power klystrons operating at a frequency of 2856 MHz. All of the high power rf is contained within the vacuum waveguide or accelerating cavities and poses no health hazard.

Magnetic fields of the order of 5 gauss at 1.4 meters developed by a large permanent magnet

used for focusing the electron beam in the klystron and 5 gauss @ 0.2 meters by electromagnets used to bend the electron beam from the gun into the linear accelerator will be present. Signs warning of this hazard are posted on entry to the klystron area, the areas beneath the klystron, and on the entry doors to the linear accelerator area where the electromagnets are housed.

Hazards	Controls
NON-IONIZING RADIATION The klystrons which provide the radio frequency power for the accelerator utilize a permanent magnet (5 gauss @ 1.4 meters) for beam focusing and provide high radio frequency power at an operating frequency of 2856 MHz.	This power is transmitted from the klystrons to the accelerating sections and electron gun via vacuum waveguides IH Field Mapping

Table 7: Non-Ionizing Radiation Hazards and Controls

4.3.2 Laser Hazard

A 2 mJoule per micropulse, up to 1500 micropulses pulses per second, 1 GW peak power, Nd:YAG laser used to excite the electron gun cathode is also a potential hazard. However, stability and timing requirements necessitate the laser light being enclosed in a temperature-regulated environment for the normal operational mode. Only trained laser users wearing protective eyewear may be inside the interlocked rooms used to contain the laser light. This is effectively a Class IV laser as defined in ANSI Z136.1-2000 and is operated as required by that standard, the BNL Laser Safety Subject Area and as described in the ATF Nd:YAG Laser Procedures.

There is a pulsed, terawatt peak power CO_2 laser, which is used to accelerate electrons in specially designed accelerator devices housed in the Experimental Area. It also presents a Class IV laser hazard and is operated with the precautions given in the ATF CO_2 Laser Procedures.

Similar precautions are taken for the light from the FEL experiments that may produce laser hazards from Class II – Class IV.

Other lasers may be used in experiments and are reviewed in compliance with the relevant subject areas, i.e. Work Planning and Control for Experiments and Operations, and Laser Safety.

Hazards	Controls
LASER A 2 mJoule per micropulse, up to 1500 micropulses pulses per second, 1 GW peak power, Nd:YAG laser (Class IV) used to excite the electron gun cathode. A pulsed, terawatt peak power CO_2 laser (Class IV) , which is used to accelerate electrons in specially designed accelerator devices housed in the Experimental Area. Light from the FEL experiments that may produce laser hazards from Class II - IV. Other lasers may be used in experiments and are reviewed in compliance with the relevant subject areas, i.e. Work Planning and Control for Experiments and Operations, and Laser Safety.	Interlocked Rooms Training Laser Safety Eyewear Enclosed Beam Paths Beam Stops Laser Tier I Inspections ATF Nd:YAG Laser Procedures ATF CO2 Laser Procedures LSO Approval of Procedures Safety inspections Work planning

Table 8: Laser Hazards and Controls

4.4 Maximum Credible Incident Assessments

4.4.1 Maximum Credible Incident Assessment for the Linear Accelerator Systems

Radiation, mainly in the form of bremsstrahlung and neutrons exist inside the Linac shield so the potential for a serious radiation accident exists if the shielding is removed. Warning signs and a search procedure prior to start up will preclude any accident due to radiation. In order to assure shielding configuration control the moving of any shielding material must be reviewed and documented by the ATF Safety Officer and RCD Technician using the (see Appendix VII) "Authorization for Work on ATF Accelerator Safety Systems."

There is also the potential for an accident due to electric shock. Preparation for this eventuality includes regular electrical safety training and training in the Electrical Safety Subject Area (Lock-out/Tag-out Requirements) for all electronic technicians and others working with high voltage. Detailed training requirements are given in Section 4.0 of the ATF Handbook. The equipment is designed with the appropriate interlocks to prevent electric shock. LOTO is the policy at BNL and any working hot is not permitted unless covered by a "hot work permit." Detailed layout and shielding studies have been made and reviewed originally by the NSLS ES&H Committee, the Physics Department's ES&H Committee, and by the BNL Laboratory ES&H Committee. The shielding configuration for the entire accelerator housed in Building 820 low bay area is shown in Figures 5 and 6.

4.4.2 Maximum Credible Incident (MCI) Assessment for the Linac Tunnel and Experimental Area

Hazards exist at the ATF that have the potential for serious injury or a fatality. The hazards that have been identified are radiation exposure, contact with high voltages, fire, or exposure to Class IV radiation from the lasers. Administrative and Engineering Controls are in place to mitigate those hazards. The Maximum Credible Incidents in these 4 areas are discussed below.

4.4.2.1 MCI for Exposure to Ionizing Radiation

The electron beam striking any part of the beam pipe or lead shield in the beam line system produces very high levels of bremsstrahlung radiation and neutrons. The protection systems described above are designed to prevent personnel from exposure to these levels. For an accident to occur, the following systems or procedures must fail.

1. The operations personnel would have to fail to carry out the prescribed search procedures; visual warning and audible warning would have to fail, too.
2. The dual electrical interlocks on the entry door, which automatically turn off power to the Linac r.f. system, must have failed.
3. The dual electrical interlock that is activated when any entry door is opened and which automatically inserts the transport line beam stop must have failed.

All of the above rely upon a proper search being carried out by the operations personnel. The only backup to this is the emergency off buttons which exist in all potential radiation areas and which will inhibit beam operation and revoke the interlock state.

4.4.2.2 MCI for Exposure to High Voltages

In Section 4.2, the modulators are identified as containing an electrical hazard of up to

50kV. A number of safety features are employed to protect personnel against accidental exposure to this high voltage. The cabinet's door lock and 208 VAC breaker share a Kirk key, which prevents operating one if the other is already open. If an attempt to open the modulator cabinet door during operation was successful, the door interlock mechanism would cause both the high voltage power supply to turn off and the charged capacitors to quickly short to ground. Simultaneous failure of these protective features is extremely remote.

4.4.2.3 MCI for Fire in Modulator Pulse Forming Network

The modulator enclosures contain pulse forming networks with several oil-filled capacitors, which have the potential to fail during operation and catch fire. A number of safety features have been incorporated into the design of the modulators to greatly lessen the probability that a capacitor failure results in a fire that spreads beyond the confines of the enclosure. The capacitors are monitored for early signs of failure, including regular visual inspection for signs of damage and continuous electrical analysis for arcing during operation. The capacitor tree is located in a non-ventilated compartment, which is monitored by a smoke detector. Activation of the smoke detector shuts down the high voltage power supply and remotely alerts the control room operator. Power to the modulators can also be shut down remotely by depressing any one of a number of emergency stop buttons. The mezzanine, in which the modulators are housed, is fully sprinklered and is continuously monitored for smoke detector and sprinkler activation by BNL's Fire Rescue group.

4.4.2.4 MCI for Exposure to Class IV Laser Radiation

The class IV lasers housed in the ATF produce invisible non-ionizing radiation that is hazardous to the eyes, even when not viewed directly. For this reason, interlocks are provided in all rooms where such beams may be present and all occupants are required to don appropriate laser eyewear whenever the room is interlocked. During the interlock procedure, a series of wall-mounted buttons must be pushed which forces the laser operator to visualize all parts of the room. Following the last interlock button push, an audible alarm sounds and a blue strobe light flashes for 15 seconds. After this warning, shutters are enabled and laser radiation is allowed to enter the room. Red "Interlocked" signs remain illuminated on the exterior thresholds of all doors to the room. In order to enter or leave the room while preserving the interlock, a "pass-through" button must be pressed prior to opening the door. In the unlikely event that a person is caught in (or attempts to enter) the room without protective eyewear, the act of opening any door will immediately drop the interlock and block the beam. Alternatively, any emergency stop button in the room may be pressed.

4.4.3 Risk Assessment

ATF Risk Assessments have been carried out and are presented below. The Risk Assessments for the maximum credible incidents are summarized in Table 9 below while the definitions are given in Table 10.

Event	Risk Category Post Mitigation	Credited Controls
Possible exposure to radiation	Low	Yes

Possible contact with high voltage	Low	No
Fire - Accelerator, Beam Transport and Experimental Area	Low	No
Fire - Control Room	Low	No
Fire - Electrical Equipment Areas, Laboratories and Laser Systems	Low	No
Personnel exposure to radiation from Class IV lasers	Low	Yes

Table 9: Summary of Risk Assessments

PROBABILITY **CONSEQUENCE**	**FREQUENT** Likely to occur repeatedly in life cycle	**PROBABLE** Likely to occur several times in life cycle	**OCCASIONAL** Likely to occur sometime in life cycle	**REMOTE** Unlikely to occur in life cycle but possible	**EXTREMELY REMOTE** Likelihood of occurrence ~ zero
CATASTROPHIC Radiological or chemical exposure causing multiple deaths or serious injury, off-site evacuation, > 100 rem to an individual, > $1,000,000 damage, > 4 mos. Facility downtime, total loss of mission data, or having a public impact that closes the Department buildings or a User Facility.	**HIGH RISK**	**HIGH RISK**	**HIGH RISK**	**MODERATE RISK**	**LOW RISK**
CRITICAL Radiological or chemical exposure causing a death or serious injury, > 25 rem to an individual, > $250,000 damage, 3 weeks to 4 months program downtime, severe loss of experimental data, or having a public impact that closes down an experiment or program.	**HIGH RISK**	**HIGH RISK**	**MODERATE RISK**	**LOW RISK**	**LOW RISK**
MARGINAL Radiological or chemical exposure causing moderate injuries, local evacuation, > 5 rem to an individual, > $50,000 damage, 4 days to 3 weeks program downtime, major loss of experimental data, or having a public impact that brings the experiment to the attention of the community and activist groups.	**MODERATE RISK**	**MODERATE RISK**	**LOW RISK**	**LOW RISK**	**INSIGNIFICANT RISK**
NEGLIGIBLE Radiological or chemical exposure causing minor injuries, no on-site or off-site evacuation, < 2 rem to an individual, < $50,000 damage, < 4 days program downtime, minor loss of experimental data, or having a public impact that is below public perception.	**INSIGNIFICANT RISK**	**INSIGNIFICANT RISK**	**INSIGNIFICANT RISK**	**INSIGNIFICANT RISK**	**INSIGNIFICANT RISK**

Table 10: Risk Ranking Matrix by Probability and Consequence

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Accelerator, Beam Transport and Experimental Area
HAZARD: Possible exposure to radiation

Hazard Impact: Possible loss of life or serious injury to personnel

---

Risk Assessment prior to mitigation:

Severity : I (X) Catastrophic II ( ) Critical III ( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C(X)Occasional D( ) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I(X) High Risk II( ) Moderate III( ) Low Risk IV( ) Routine

---

Mitigating Factors: Search procedures, audible announcement, Experimental Hall lights go out, and closed interlocks are required prior to electron beam entering the Hall. Crash buttons (Emergency Stops) are provided in room. Radiation monitoring and shielding ensure no risk to the public outside the secured areas.

Risk Level following mitigation:

Severity : I(X) Catastrophic II( ) Critical III( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D( ) Remote
E(x) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III(x) Low Risk IV( ) Routine

---

Shielding and Interlocks need to be in the ASE.

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Electrical distribution system and electrical equipment
HAZARD: Possible contact with high voltage

Hazard Impact: Possible loss of life or serious injury to personnel

---

Risk Assessment prior to mitigation:

Severity: I ( ) Catastrophic II (X) Critical III ( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C(x)Occasional D( ) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I( ) High Risk II(X) Moderate III( ) Low Risk IV( ) Routine

---

Mitigating Factors: All power supplies are protected with physical barriers wherever there is a possibility of exposure to voltages exceeding 50 volts. In situations where extremely high voltages are present, such as the klystron modulators, door interlocks and automatic and manual grounding is provided. Working hot is discouraged and requires special training and approved procedures. High voltage and, or high current equipment is only accessed using BNL standard Lock-out Tag-out procedures. All affected personnel are trained to follow these procedures.

Risk Level following mitigation:

Severity : I( ) Catastrophic II(X) Critical III( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D( ) Remote
E(x) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III(x) Low Risk IV( ) Routine

---

None of these controls need to be in the ASE.

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Accelerator, Beam Transport and Experimental Area
HAZARD: Fire

Hazard Impact: Possible threat to personnel safety or equipment loss

---

Risk Assessment prior to mitigation:

Severity : I ( ) Catastrophic II (X) Critical III ( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C(X) Occasional D( ) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I( ) High Risk II(X) Moderate III( ) Low Risk IV( ) Routine

---

Mitigating Factors: Most of the equipment associated with the accelerator and beam transport systems is metallic and is under concrete where it is somewhat protected from an external fire. Smoke and heat detectors are provided in all areas and there is an annunciator and signal system tied to the Site fire alarm system. Portable fire extinguishers are located throughout the area. The maximum travel distance to a fire extinguisher is 75 ft.

The Experimental Area is protected by a sprinkler system as well as having smoke and heat detectors.

All ATF personnel are trained in BNL Emergency Response Procedures.

Risk Level following mitigation:

Severity : I( ) Catastrophic II( ) Critical III(x) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D(X) Remote
E(x) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III(X) Low Risk IV( ) Routine

None of these controls need to be in the ASE.

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Control Room
HAZARD: Fire

Hazard Impact: Possible threat to personnel safety, equipment loss and program downtime.

Risk Assessment prior to mitigation:

Severity : I ( ) Catastrophic II (X) Critical III ( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C(X) Occasional D( ) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I( ) High Risk II(X) Moderate III( ) Low Risk IV( ) Routine

---

Mitigating Factors: Smoke and heat detectors are situated in the Control Room and adjacent areas. Activation of any fire detection sensor automatically sounds local alarms and transmits an alarm to the BNL Fire and Rescue Group. Portable fire extinguishers are located in the Control Room and adjacent area. There are two exits from the Control Room.

The total value of equipment situated in the Control Room does not exceed $300,000 and all of it could be replaced within a six month period.

All ATF personnel are trained in BNL Emergency Response Procedures.

Risk Level following mitigation:

Severity : I( ) Catastrophic II( ) Critical III(x) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D(X) Remote
E( ) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III(X) Low Risk IV( ) Routine

---

None of these controls need to be in the ASE.

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Laser Equipment Areas
HAZARD: Personnel exposure to radiation from Class IV lasers

Hazard Impact: Eye or skin exposure to laser light

Risk Assessment prior to mitigation:

Severity : I ( ) Catastrophic II (x) Critical III ( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C(x) Occasional D( ) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I( ) High Risk II(x) Moderate III() Low Risk IV( ) Routine

---

Mitigating Factors: All personnel entering or working in laser equipment areas are required to wear protective eyewear. They are also protected from accidental exposure to laser radiation by transmitting the laser beams inside opaque enclosures and by providing interlocked areas to house the lasers.

The laser safety and access control system is designed to be failsafe. Unauthorized entry into these secured areas will automatically cause a beam stop to block the beam so that the hazard is removed.

All laser operators undergo "Laser Safety Awareness" training and undergo an eye exam. As part of their training and certification, all personnel at the ATF must demonstrate an understanding of the procedures.

Risk Level following mitigation:

Severity : I( ) Catastrophic II(x) Critical III() Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D() Remote
E(x) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III(X) Low Risk IV( ) Routine

The interlocks need to be in the ASE.

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Electrical Equipment Areas, Laboratories and Laser Systems
HAZARD: Fire

Hazard Impact: Possible threat to personnel safety, equipment loss and program downtime.

Risk Assessment prior to mitigation:

Severity : I ( ) Catastrophic II (X) Critical III( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C(X) Occasional D( ) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I( ) High Risk II(X) Moderate III( ) Low Risk IV( ) Routine

---

Mitigating Factors: The trailer, the gun laser area and the equipment mezzanine are provided with smoke detection and also fire protection via a sprinkler system. Portable fire extinguishers are located throughout the area and the maximum travel distance to a fire extinguisher is 75 ft.

Gun and Linac modulators have been equipped with crash buttons to remove all sources of electrical power.

All ATF personnel are trained in BNL Emergency Response Procedures.

Exiting for fire emergencies is in compliance with the Life Safety Code NFPA101, 1994.

Activation of any fire detection sensor or alarm automatically sounds local alarms and transmits an alarm to the BNL Fire and Rescue Group.

Modulators were upgraded following the 2009 fire which includes measures taken to remove combustible material from critical areas, isolation of the capacitor bank compartment from other components, and limiting air flow to the capacitors.

Risk Level following mitigation:

Severity : I( ) Catastrophic II( ) Critical III(x) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D(X) Remote
E( ) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III(X) Low Risk IV( ) Routine

None of these controls need to be in the ASE

4.5 Engineered, Administrative, and Credited Controls

4.5.1 Introduction

All of the safety hazards at the Accelerator Test Facility are treated in essentially similar ways with regard to personal safety barriers such as shielding for radiation hazards and covered closed areas for electrical or laser safety. Controls are either engineered or administrative measures (procedures, training, etc.) that eliminate, control, or mitigate hazards from operations. At the ATF the engineered controls consist of separate systems of interlocks for radiation and lasers, locks for access control, and key control while procedures have been developed for operation of equipment, sweeps, and control of keys. Maximum Credible incidents are discussed in sections 4.4.2.1. – 4.4.2.4. above on pages 31 – 32.

Comprehensive procedures have been developed for operations of the accelerator, responses to faults or malfunctions, maintenance, testing of interlocks, and the operation, maintenance and alignment of lasers. These are reviewed, revised as necessary, and published on the ATF's ES&H web pages. Operators and staff are trained in the use of these procedures as applicable. All ATF staff receives additional training commensurate with their responsibilities and the organizational needs. Requirements are detailed in the ATF Handbook section 4. The Physics Department's Safety and Training Office in conjunction with the ATF Safety Officer monitor and track training requirements and ensure qualifications are appropriate and current.

4.5.2 Radiation Shielding

Calculations are given in Appendix V. The shielding used ensures that there is no exposure beyond the permitted levels to the public, ATF staff, and users. Staff and users are trained (ATF Facility Specific Training, i.e. ATF Awareness Training) to respect and maintain the ATF's primary shielding configuration. Primary shielding consists of the lead, concrete and other materials that enclose the ATF's accelerator, beam lines and experimental areas, as defined in this SAD. If there is any need to alter or remove primary shielding, a shielding permit (Appendix VII) must be in place before the work may begin. This authorization describes the job, the system affected, and the safeguards put into place to protect the workers during reconfiguration. The original permit is posted at the work site, and a copy is posted in the control room to notify the accelerator operator. Prior to the restart of Linac operations, the close out conditions of the permit must be satisfied. This typically includes inspection by ESH personnel, but may also include fault studies and additional documentation. This permit is reviewed by the Radiological Control Division's Facility Representative. Minor changes to shielding are done between ATF ESH officer and the lower-level RCD Supervisor using the permit. Minor changes that the RCD supervisor deems above his expertise are either resolved by review from a higher RCD supervisor or sent to the Physics Department's ESSH Committee. Major changes go straight to Physics ESSH Committee.

4.5.3 Accelerator Interlocks and Security

The ATF employs interlocks for the control of areas where laser, ionizing and non-ionizing radiation is present. These systems are designed, installed, maintained, and tested in compliance with all applicable BNL and DOE policies and regulations. Areas that are interlocked include the Experimental Hall and Laser Areas. Sweeps are performed to ensure no personnel are in these areas when operations commence. The procedure "ATF Laser Interlock System Search Patterns" is reviewed, revised as necessary, and published on the ATF's ES&H web pages. The sweep for the laser interlocks simultaneously satisfies the requirements for interlocking the Experimental Hall for

radiation purposes.

Access to the Experimental hall and Laser Areas is controlled by locks on all external entry points. In addition there are locks on the attic hatch, a single entrance point to the 'caged-in' area above the experimental hall where wiring, utilities, and signal wires are kept. Access to the attic involves the use of a ladder, requires proper authorization, and acquisition of the controlled key that unlocks the entrance. Check-off that this area is properly locked is part of the "Checklist for Operating at High Energy in Bldg. 820 Experimental Area" from the "Procedure for Operation of the Accelerator Test Facility.

The primary method of securing and tracking ATF Linac and laser security keys is via the Controlled Key Box in the ATF control room. This electronic key box uses a fingerprint reader to allow access only to authorized operators and staff. When entry is granted, the key box computer unlocks the electric door strike and automatically records the time, date, keys taken, and operator's name. The same process is applied when the keys are returned so that a complete log file is maintained.

In the event of a software or hardware failure, the key box can be accessed with a master key (normally locked in a secondary box). ATF personnel are then instructed to record the use of security keys in a written log until the key box has been returned to service.

The interlocks, securing of keys, and locked entrances are all credited controls as they reduce the risks as detailed on the Risk Assessments, pages 34 – 39.

4.5.3.1 Radiation Security

4.5.3.1.1 Securing the Linac Gun Area

Since the electron gun area is a controlled area and has the potential of becoming a high radiation area if certain lead shielding is removed, it is a fenced and locked area. Removal of lead requires a safety authorization form, a copy of which is given as Appendix VII. The gun hutch (see Figure 7) is secured using one of the procedures described in the ATF Laser Interlock System Search Procedure. Completion of the search culminates by depressing of a button on a control box adjacent to the last exit door either inside or outside the gun hutch. If anyone for any reason wishes to stop operation of the laser they may do so by depressing any of a number of emergency stop buttons situated at convenient and clearly marked locations in and around the gun hutch, the Nd:YAG room and in the experimental area. The gun hutch door is provided with standard door hardware to allow for fast exit in an emergency.

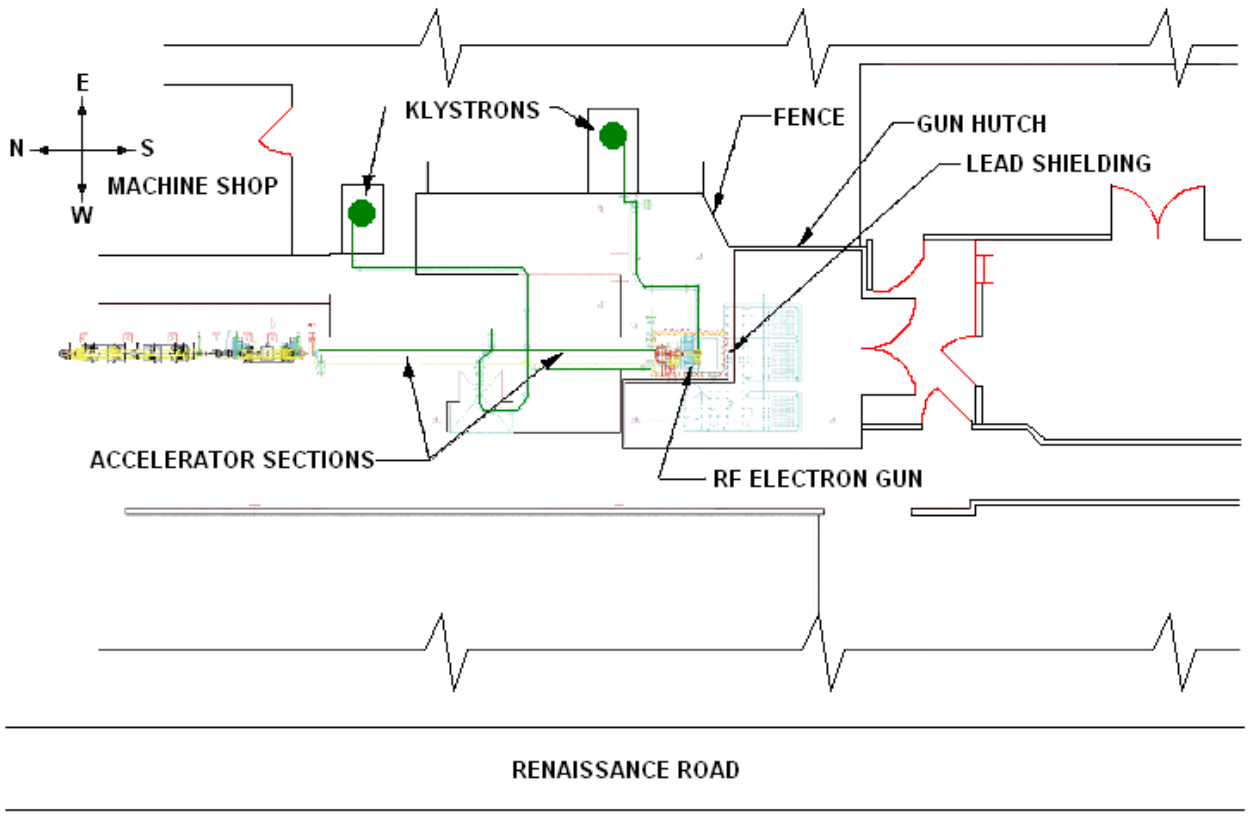

Figure 7: ATF, Building 820 Electron Gun Area Arrangement

If the gun hutch entry door is opened while the search is being carried out, the search is aborted and has to be restarted.

4.5.3.1.2 Securing the Experimental Area

Since this is a primary radiation area, it is protected by stopping the electron beam in either a fixed or movable beam stop situated in the high energy beam transport line. Any unauthorized attempt to enter the experimental area will invoke the engineering controls which cause the movable beam stop to be inserted and will also automatically turn off the contactor providing power to the klystron modulators. Dual electrical interlocks are provided on both the electron beam stop and the entry doors to the experimental area. Each electrical circuit operates an independent set of power contactors in the supplies to the modulators. One of the electrical circuits also inserts a beam stop situated downstream of the linac.

Before the electron beam can be delivered to the experimental area, a search is made. In order to ensure a proper search, reset buttons are provided which require the person carrying out the search to cover all regions of the experimental area. These have to be reset in a prescribed sequence, and in a prescribed time. The person carrying out the search exits through the entry door situated either at the northeast or southwest corner of the experimental area. After exiting and closing the door, a reset button must be pressed which sets off an annunciator in the experimental area that sounds for 15 seconds. If anyone for any reason wishes to stop operation they may do so by depressing any of a number of emergency stop buttons situated at convenient and clearly marked locations within both

the Linac and experimental areas. Both entry doors are interlocked and both are provided with an emergency panic release system to allow fast exit in an emergency. If either of the entry doors is opened while the search procedure is in progress the search is automatically aborted and has to be restarted. The details for securing the ATF Experimental Area are given in the Operation of the ATF Procedure.

In order to carry out beam studies in the Linac tunnel before the experimental hall, it is necessary to insert the movable beam stop. Entry to the tunnel is via a dual electrically interlocked movable concrete "plug" door. When the movable beam stop is inserted and the plug door is in place with the interlock complete it is possible to operate the modulators and beam transport systems in order to carry out beam diagnostic studies in the tunnel while the experimental area is open. These procedures must be followed in order to operate in this Mode.

All ATF Radiation Interlock Systems had originally been reviewed and approved by the BNL Interlock Review Committee, later updates were reviewed and approved by the NSLS, and currently, the C-AD Interlock Group has the responsibility.

4.5.3.2 Securing the Laser Equipment Rooms

Some of the lasers housed in the laser rooms are classified as Class IV lasers as per ANSI Z136.1-2000. Therefore, all entry doors to the laser equipment rooms are electrically interlocked so that an unauthorized entry will cause a beam stop to be inserted in the laser beam path. The ATF Laser Interlock System Search Procedure -describes how laser areas are secured. In addition, persons working in this area are required to wear protective eyewear whenever the lasers are capable of emission. They are also required to undergo training as specified in Sections 4.00 and 4.01 of the ATF Handbook. Furthermore, the beam transport path between rooms is enclosed, with interlocks being provided for the enclosures. The ATF Procedures related to lasers give an overall description of the lasers to be used in the experimental program at the ATF and all associated safety, operation and maintenance procedures.

5. QUALITY ASSURANCE

The Accelerator Test Facility is part of the Physics Department. The BNL Quality Assurance Program applies to the work performed on the project. The ATF management is responsible for the quality of construction, the operation of the equipment and the work processes in the facility. Responsibility for quality is delegated through the line staff positions and they are responsible for the quality of their own work. ATF accelerator components are evaluated for quality assurance categories A-1 through A-4 as per BNL QAC-301. The ATF shall comply with the required QA elements of DOE Order 414.1.

6. POST-OPERATIONS PLANNING

At the appropriate time a full decommissioning and decontamination plan will be developed using the Subject Area, Work Planning and Control for Experiments and Operations. The ATF is a facility with standard industrial hazards, lead for shielding, and very low levels of activation are expected at ATF decommissioning. The ATF will comply with the rules and requirements for waste that are in effect at the time of decommissioning. Nearly all the lead will be recycled or used elsewhere in the BNL complex, there should be no more than a cubic meter of radiological waste and suspect metal.

7. ASSOCIATED DOCUMENTATION

BNL documentation is available on their websites while the Physics Department keeps its and the ATF's documentation in the Physics Department's Safety & Training Office in Building 510.

1. BNL Standards Based Management System
2. BNL Subject Areas
3. Physics Department Policies and Procedures
4. ATF Handbook
5. ATF Procedures

APPENDIX I

Fire Hazard Analysis
Building 820
Accelerator Test Facility (ATF)

Pages 40-84
(Please see separate PDF Document)

Fire Hazard Analysis
Building 820
Accelerator Test Facility (ATF)

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Date of Report: September 2009

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1.0 OVERVIEW AND RECOMMENDATIONS

1.1 Purpose and Methodology

A Fire Hazard Analysis (FHA) was performed for Building 820, Accelerator Test Facility (ATF) at the Brookhaven National Laboratory (BNL), Upton, NY. This report fulfills the requirement for documentation of an FHA as outlined in DOE Order 420.1, Facility Safety. This FHA assesses the risk from fire in Building 820 to ascertain whether the facility meets the objectives of DOE Order 420.1 and the Brookhaven National Laboratory (BNL) Fire Safety Program. The fundamental goal of the BNL Fire Safety Program is to control fire risks such that:

1. Public and employees are not unreasonably endangered by fire;
2. Vital Laboratory missions are maintained without significant interruption from fire;
3. Property losses are limited to less than $1 million dollars per occurrence, and lower when justified by cost-effective, risk reduction measures;
4. Damage to the environment is averted; and
5. The potential for occurrences of fires are avoided whenever economically feasible.

This FHA is an evaluation of the fire hazards (1) that expose Building 820 and (2) that are inherent in the building or operations. The adequacy of the fire safety features in the building and the degree of compliance of the facility with specific fire safety provisions in DOE orders, and related engineering codes and standards, were determined. The results of the analyses are presented in terms of the fire hazards present, the potential extent of fire damage, and the impact on employee and public safety.

The general approach taken to complete this evaluation involved the identification of fire hazards in the building and the fire protection features required to mitigate the adverse consequences of a fire. A determination was made as to the adequacy of the proposed fire protection features to effectively control the fire hazards. Concerns for the protection of safety systems, critical processes, and life safety of building occupants from fire were essential considerations in the analysis. Compliance was determined by a comparison of existing conditions found during the site visits with current code requirements. Where conflicting requirements were found the more conservative requirements were used in this evaluation.

Photograph #1 – Building 820

The MPFL scenario was based on a qualitative consideration of several factors; the potential to reach flashover conditions based on combustible loading and the geometry of the space(s) under consideration; adequacy of passive protection features; and continuity of combustibles.

The MCFL scenario is one in which automatic suppression systems function as designed. Since properly designed and installed sprinkler systems should limit the fire growth and/or damage to the design area of the system, this floor area is used in the determination of MCFL potentials when protected by automatic sprinkler systems. Without sprinkler protection the MCFL is the same as the postulated MPFL for that area.

MPFL and MCFL potentials were determined based on an average dollar density of the building replacement value divided by the floor area of the building. Building values were obtained from 2004 replacement costs. The content and equipment values were calculated based on the following assumptions:

- An average of $\$20/ft^2$ for content and equipment value within predominantly office or support areas.
- An average of $\$100/ft^2$ for content and equipment value within the laboratory and experimental areas of the building, assuming no high dollar equipment present.

- Input from facility management on the overall all value of equipment within the building

The above cost assumptions are considered adequately conservative to address the requirement to include decontamination and cleanup costs.

A qualitative assessment of the risk presented by conditions found to be deficient was also performed and is included in Section 1.3, Findings and Recommendations. This assessment was made by assignment of a risk assessment code (RAC). The RAC methodology is used in a number of industries as a tool to qualitatively prioritize deficiencies and corrective actions and is derived as follows:

1. Hazard Severity. An assessment of the worst potential consequence, defined by degree of occupational injury, illness or property damage which is likely to occur as a result of the deficiency. Hazard severity categories shall be assigned by roman numerals according to the following criteria:

   a. Category I. May cause death, permanent total disability, or loss of a facility/asset.

   b. Category II. May cause permanent partial disability, temporary total disability in excess of 90 days (severe injury or severe occupational illness), or major property damage.

   c. Category III. May cause minor injury, occupational illness, or property damage.

   d. Category IV. Presents minimal threat to personnel safety or health, or property, but is still in violation of a standard.

2. Mishap Probability. The probability that a hazard will result in a mishap or loss, based on an assessment of such factors as location, exposure (cycles or hours of operation), affected populations, experience, or previously established statistical information. Mishap probability shall be assigned an English alphabet symbol according to the following criteria:

   a. Subcategory A. Likely to occur immediately or within a short period of time. Expected to occur frequently to an individual item or person or continuously to a fleet, inventory or group.

   b. Subcategory B. Probably will occur in time. Expected to occur several times to an individual item or person or frequently to a fleet, inventory or group.

   c. Subcategory C. May occur in time. Can reasonably be expected to occur sometime to an individual item or person or several times to a fleet, inventory or group.

   d. Subcategory D. Unlikely to occur.

3. Risk Assessment Code. Using the matrix shown below, the RAC is expressed as a single Arabic number that is used to help determine hazard abatement priorities.

Hazard Severity	Mishap Probability			
	A	B	C	D
I	1	1	2	3
II	1	2	3	4
III	2	3	4	5
IV	3	4	5	6

RAC Definitions

1-Critical
2-Serious
3-Moderate
4-Minor
5 & 6-Negligible

1.2 Summary

Building 820, Accelerator Test Facility is engaged in support activities for the Physics Department at the Brookhaven National Laboratory.

The original building was operational in 1957 and is 29,507 square feet in area. Building 820B is 726 square feet The building is one story (including a high bay) with a small mezzanine area.

The descriptions are based on field surveys, a review of the as-built documents, and discussions with BNL staff. This assessment and FHA demonstrates that a general achievement of reasonable and equivalent level of fire safety that meets DOE improved risk objectives is not being met, as noted within this document.

Overview of the BNL – Near Building 820

This Fire Hazards Analysis (FHA) has been performed to comprehensively assess the risk from fire in Building 820. The FHA includes an analysis of the fire and life safety features of the facility to determine the level of compliance with DOE Order 420.1 Fire Protection objectives.

Based on the analysis, it has been determined that Building 820 is generally in compliance with DOE Order 420.1 Fire Protection objectives. The following recommendations are the result of this evaluation.

1.3 Findings and Recommendations

1.3.1 New Findings and Recommendations

Finding: The building is not provided with a lightning protection system.

Hazard Severity	I
Mishap Probability	C
Risk Assessment Code	2

Recommendation HAI-09-820-01: A lightning protection system should be installed in accordance with NFPA 780 (See Section 6.6.1).

Finding: The building is not fully protected with automatic sprinklers.

Hazard Severity	I
Mishap Probability	B
Risk Assessment Code	1

Recommendation HAI-09-820-02: The unsprinklered portions of the building should be provided with an automatic sprinkler system in accordance with NFPA 13, or a DOE exemption should be obtained, (See Section 5.1.3, and 7.5.4).

Finding: The "Gun Hutch" in the LAG Laser Lab area is not protected with smoke detection as are the other rooms in this area.

Hazard Severity	III
Mishap Probability	B
Risk Assessment Code	3

Recommendation HAI-09-820-03: The "Gun Hutch" in the LAG Laser Lab area should be protected with smoke detection similar to the other rooms in this area, (See Section 5.3).

Finding: Trees are within 30-feet of Modular Building 355.

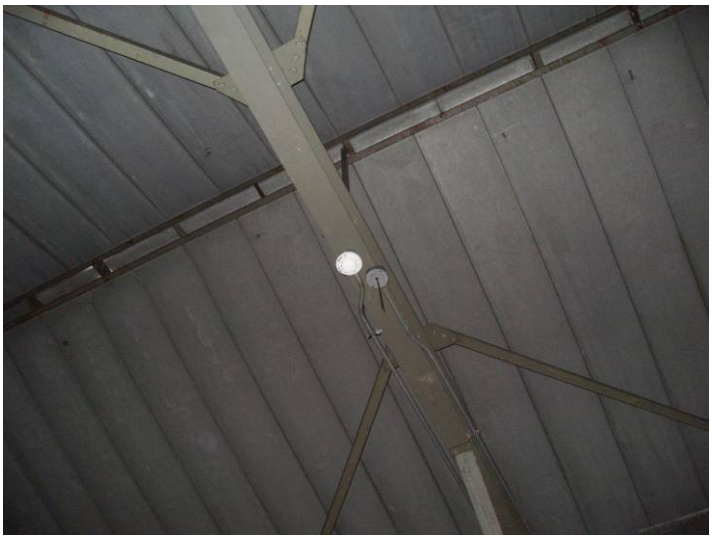
Hazard Severity	III
Mishap Probability	B
Risk Assessment Code	3

Recommendation HAI-09-820-04: The trees that are within 30-feet of Modular 355 should be thinned.

Finding: The heat detection in Building 820B are approximately 4-feet below the roof line.

Hazard Severity	III
Mishap Probability	B
Risk Assessment Code	3

Recommendation HAI-09-820-05: The heat detectors should be raised to be within 20-inches of the ceiling in accordance with NFPA 72, Section 5.6.3.2, (See Section 5.3).



The following is a summary of recommendations and their relative priority.

Rec.No.	Recommendation	RAC
HAI-09-820-01	Lightning Protection System	2
HAI-09-820-02	Automatic Sprinkler Protection	1
HAI-09-820-03	Smoke detection needed in “Gun Hutch” room	3
HAI-09-820-04	Trees within 30-feet of Modular 355	3
HAI-09-820-05	Location of heat detectors	3

1.3.2 Outstanding Recommendations from Previous Reviews

None from either Factory Mutual or Professional Loss Control.

2.0 SCOPE

This FHA is based on information supplied by laboratory personnel, a survey of the facility conducted in April 2009, and a review of available drawings.

The following codes and standards were utilized for this evaluation:

The Building Code of New York State 2007 Edition (BCNYS)

International Code Council (ICC), International Building Code (IBC) 2007 Edition;

ICC, International Fire Code (IFC) 2003 Edition

National Fire Protection Association (NFPA) Codes, Standards, and Recommended Practices – See Section 9 (Reference Documents) of this report for a complete list.

3.0 LOCATION

Building 820 is located in the central region of the laboratory. BNL is a 5,000 acre site owned by the Department of Energy and operated by Brookhaven Science Associates. BNL is located in Upton, New York.

CONSTRUCTION

3.1 Occupancy Classification

Building 820, Environmental Waste Tech Center, is classified as follows:

Building Number	Description	Occupancy Type – NFPA 101	Occupancy Type - BCNYS
Building 820	Laboratory with associated support areas	Business	Business
Modular's (820M & 321)	Offices	Business	Business

Note: The building is classified as a Business Occupancy to be consistent with the other laboratories at the BNL. There are areas of the building that are closer to industrial occupancies, but classifying the overall building as a business occupancy does not have an impact to the overall evaluation of this facility.

3.2 Construction Type

The building is corrugated metal walls and steel deck roof on unprotected steel.

The building construction type is BCNYS Type II-B and NFPA Type II (000).

The two modular's are of wood frame construction.

The building construction type for the modulars is BCNYS Type V-B and NFPA Type V (000).

Combustible loading varies throughout the building from light (mechanical spaces and most laboratory areas) to moderate (offices); generally the combustible loading is acceptable.

Life Safety Code

The LSC does not specify a minimum construction type for business occupancies [§39.1.6]. Thus, the existing construction complies with LSC requirements.

Building Code of New York State

Section 503 and Table 503 of the BCNYS contain criteria for the allowable height and area of buildings based on their occupancies and construction type.

The BCNYS, Section 506 permits an increase in allowable areas for buildings that have more than 25 percent of their perimeter on a public way or open space having a minimum width of 20 feet [IBC, §506.2]. The area increase due to frontage is determined in accordance with the following equation:

$I_f = 100[F/P - 0.25]\ W/30$, where:

I_f = Area increase due to frontage.

F = Building perimeter which fronts on a public way or open space having 20 feet open minimum width (feet).

P = Perimeter of entire building (feet).

W = Width of public way or open space (feet). The width (W) must be at least 20 feet and W/30 cannot exceed 1.0.

Building 820 is 29,507 square feet total which is not within the base allowable area of 23,000 square feet for Type II-B construction, thus it is necessary to apply the increase for public way.

$I_f = 100[1000/1000 - 0.25]\ 20/30$

$I_f = 50\%$

Note: Perimeter figure approximate.

Table 4.2-1. Allowable Height and Areas for BCNYS Group B

	Group B
	Type II-B
Base Height	**4 stories**
Base Area (ft^2)	**23,000**
Modified Area (ft^2) based on public way increases	**34,500**

The building is within the modified area based on public way increases.

International Building Code

Based on a B occupancy and Type II-B construction, Table 503 of the IBC permits the maximum allowable area to be 23,000 square feet and a height of 4 stories. Since Building 820 is 29,507 square feet which is not within the base allowable area of 23,000 square feet, it is necessary to apply the increase for public way.

Section 506 and 507 of the IBC contain allowable area increases based on the location of the building and sprinkler protection, if provided. The areas limited by Table 503 can be increased due to frontage and automatic sprinklers based on the following:

$A_a = A_t + [A_t I_f / 100] + [A_t I_s / 100]$

Where:

A_a = Allowable area per floor

A_t = Allowable floor area per Table 503

I_f = Area increase due to frontage (percent) as calculated in accordance with 506.2

I_s = Area increase due to sprinkler protection (percent) as calculated in accordance with Section 506.3.

$I_f = 100[F/P - 0.25] W/30$

Where:

I_f = Area increase due to frontage

F = Building perimeter which fronts on a public way or open space having 20 feet open minimum width

P = Perimeter of entire building

W = Width of public way

The building is sufficient based on public way increases (same formula as for the New York Code).

3.3 Passive Fire Protection

Passive fire protection features include fire-resistive construction, fire doors, fire windows, and fire and smoke dampers. The features are provided to limit fire spread and damage from the area of fire origin to other portions of the building.

3.3.1 Fire Areas

Building 820 is not separated by fire barriers, for area separation purposes.

Building 820 complies with the codes of record with respect to occupancy separations. There are no areas in this facility that are defined as incidental or accessory occupancy use areas as noted in BCNYS “§302.1.1” or NFPA 101 §6.1.14.1.2 and “§6.1.14.1.3.”

A fire area is defined as a portion of a building that is bounded by a combination of fire-resistive walls and floor/ceiling assemblies, and/or exterior walls. In DOE facilities, fire areas are typically provided for property protection. The Implementation Guide for DOE Order 420.1

requires credited fire areas to be separated from the remainder of the building by a minimum of 2-hour fire barriers (walls and horizontal assemblies). Fire areas may also be provided for compliance with building code limitations for building additions.

4.0 FIRE PROTECTION

Existing fire protection systems that provide protection to full or segmented portions of this facility can be classified in four categories; Automatic Fire Suppression Systems, Fire Alarm Systems, Automatic Detection Systems, and Fire Extinguishers. The following is a description of the existing installed systems in the building.

4.1 Automatic Fire Suppression Systems

4.1.1 Site Water Supply

BNL has a combination domestic and fire protection water supply system. The system is supplied by several deep wells and is stabilized by two elevated water storage tanks (one 1 million gallon and one 300,000 gallon capacity). The wells have electric primary drivers and a limited number have backup internal combustion drivers. The system can sustain three days of domestic supply and a maximum fire demand (4,000 gallons per minute (GPM) for 4 hours) for BNL with two of the system's largest pumps out of service and one storage tank unavailable. The piping distribution network is well gridded. The distribution system in the vicinity of Building 820 has a static supply pressure of approximately 57 pounds per square inch (PSI) at low elevated tank levels; and approximately 65-70 psi normally. The water supply system in the area can supply about 5,500 GPM at 20 PSI (based on the Water Distribution Model Analysis developed by the Fire Protection Engineering Group during the summer of 2004.)

Frost proof fire hydrants are provided within 300 ft of all sides of the building as follows:

- North – One, about 160-feet to the north
- South – None but one is a the SW corner
- East – None
- West – Two, one at about 80-feet and one at about 200-feet.

Frost proof hydrants are needed since the frost line extends to 4 feet below the surface in the winter. BNL and the local Suffolk County Fire Departments use National Standard Thread couplings.

BNL's F&O Division maintains the water supply system. BNL's Fire/Rescue Group conducts valve inspections and annual flow tests on the distribution system to ensure reliability of firefighting water supplies.

4.1.2 Building Water Supply and Fire Department Connection

Building 820 is partially protected with automatic sprinklers.

4.1.3 Sprinkler Systems

The building is partially protected with automatic sprinklers, via a 6-inch Reliable Model E Alarm Check Valve with a 4-inch fire department connection, areas provided with sprinklers include:

- Mezzanine area in Building 820, high bay
- Experimental Hall within the concrete vault
- Experimental Hall within the three CO2 Laser Rooms
- Module 355

A recommendation has been submitted to provide sprinklers in all portions of the building **(See Recommendation HAI-09-820-02)**.

4.1.4 Other Suppression Systems

There no special hazard extinguishing systems in the facility.

4.2 Fire Alarm Systems

4.2.1 Building Fire Alarm System

The Building is provided with an automatic fire alarm system, refer to Section 5.3. There is one Fire Alarm Control Panel for the building:

- Thorn Multi-zone 20, panel #102

5.2.2 Site Fire Alarm System

Brookhaven National Laboratory is configured as a Proprietary Supervising Station. The system utilizes a dedicated multiplexed network of data-gathering panels connected to legacy fire alarm panels and new analog fire alarm panels that both communicate using IP monitoring points reporting over a combination of copper and fiber media. The network utilizes Andover Continuum products with fault tolerant Marathon servers.

Two mirrored servers are located in separate buildings. If the lead server fails the system automatically switches over to the backup server. The Site Fire Alarm System operates on a fault tolerant Ethernet infrastructure that utilizes network switches and fiber wiring between each of the major components.

The Site Fire Alarm System monitors legacy fire alarm panels located throughout BNL by using the existing site telephone cable plant. RS232 signals are sent via full duplex line drivers. Each fire alarm panel has two channels connected to the Site Fire Alarm System. The panels are divided into 8 communication “loops”, with each loop monitoring between 15 and 28 fire alarm panels. It is currently monitoring 9,700 points. Recent installations have two channels directly installed at each newly installed panel, without using existing copper lines. Response time from alarm at the panel to alarm indication at the Supervising Station is less than 82 seconds, which is within the 90 seconds allowed by NFPA 72.

4.3 Automatic Detection Systems

The automatic detection system consists of smoke and heat detectors (mostly heat detectors) in select areas of the building. Manual pull stations are also provided in the building and connected to the FACP. Heat detection is provided in the following areas:

- Modular Building 820M
- Building 820A
- Building 820, high bay
- North side tunnel (smoke detection)
- Module 351 (heat and smoke detection)
- Connecting space between Modular 355 and Storage Building
- YAG Laser Clean Room (smoke detection), also includes the subfloor in this area
- YAG Laser Rooms, (except Gun Hutch Room)
- Control Room for the accelerator (smoke detection)
- Experimental Hall within the concrete vault (in addition to the sprinklers)
- Experimental Hall within the three CO2 Laser Rooms (in addition to the sprinklers)
- Building 820B

Note: The heat detectors in Building 820 B/821 are located 4-feet below the ceiling in violation of NFPA 72, **(See Recommendation HAI-09-820-05)**

4.4 Fire Extinguishers

Fire extinguishers are provided in the building. The location and placement of portable fire extinguishers is in accordance with NFPA 10, *Standard for Portable Fire Extinguishers*.

5.0 FIRE HAZARDS

Fire hazard potentials are classified into the following major categories; Special Occupancies, Unique Fire Hazards, Housekeeping in Vital Areas, Building Materials, Exterior Exposure Hazards, Natural Phenomenon Hazard Exposure, Toxic Fire Potential, Biological Fire Potential, and Radiation Fire Potential. The following is an evaluation of Building 820 for each category.

6.1 Special Occupancies

Special occupancies include: instrumentation and data processing equipment, vital and important records, trailers, cooling towers, electrical substations, flammable liquid and gas storage, cables and raceways. The special occupancies applicable to Buildings 820 are expanded upon in Sections 6.1.1 thru 6.1.7, below.

Building 820 is managed by the Physics Department, with space divided between the Accelerator Test Facility (820, 820M, 820B, trailer 355) and NSLS (820A, trailer 351). Details on the occupancy of the building are as follows:

Main Building – Building 820

The main building is protected with heat detection at the roof line. A 20-ton bridge crane is provided for the building. Within the building there is an interior room that's similar to a building within the building that was utilized by the Collider/Accelerator Department but that is now vacant. It is used temporarily for the storage of low-value equipment for the ATF department. There is nothing stored on top of the roof/ceiling of this interior room.

On the North side of the building there is a tunnel that leads to the storage building. This tunnel is 75-feet in length, and exceeds the requirements for a dead end corridor. The tunnel has limited combustibles and is protected with smoke detection.

The high bay portion of Building 820 has a linear accelerator tunnel. On the top of the tunnel there is a 10-foot by 75-foot mezzanine that is used for high energy physics experimentation. The mezzanine is protected with automatic sprinklers and smoke detection. The area was recently involved in a fire and is in the final stages of being renovated due to the damage from the fire. The room contains power, control and instrumentation equipment for the accelerator. The area is provided with an Emergency Power Isolation (EPO) switch. The space is also provided with a secondary exit from the back of the mezzanine that leads to the floor via a ladder.

There is the YAG laser clean room in the high bay space that contains a Class IV laser. The area has a non-combustible raised floor with smoke detection beneath. The area has high temperature stability due to the operations within this room.

The YAG laser area contains three rooms and a vestibule that contains a laser lab. This area does not have a raised floor. This is the final laser delivery area before the accelerator gun.

The control room for the accelerator does not have a raised floor and contains instrumentation and power controls for the accelerator. The room is provided with an emergency exit from the rear of the space.

The accelerator and lasers would be considered high value equipment.

The experimental hall is a 1980's addition to Building 820. It is basically a concrete vault that is highly congested. It contains the single beam from the accelerator that is then directed to one of three beam lines that generally have an interaction point within this hall. There is an approximately 6-foot by 2-feet by 7-foot (long) polyethylene shielding wall within this space. This wall is acceptable based on the presence of the automatic sprinklers within this experimental hall.

Also within the experimental hall there are three CO2 Laser rooms that are all protected with smoke detection and automatic sprinklers. One of the three rooms is provided with a 1-ton crane. A pulse forming network is filled with distilled water within this area. A Marx Generator is located outside of this area (within the high bay) and contains 500-gallons of inhibited transformer oil that has a flash point of 295 degrees F. The unit is provided with a steel secondary containment vessel.

Building 820A

Building 820A is utilized for light source storage. It is a high bay facility. Storage is on steel racks to 8 and 10-feet. There is also the storage of materials on steel shelves to 8 and 10-feet. Higher value storage is within wire cages. The storage tends to be mostly Class I and Class II commodities, per NFPA 13 with some Class III commodities. A small room within this building contains an air compressor. The high bay section is provided with a 2-ton bridge crane.

The building is protected with an automatic fire alarm system consisting of heat detectors at the ceiling.

Building 820B

Building 820 B contains the storage of spare parts for the Physics Department, mainly of low value for the ATF. The building also contains a small mezzanine that has storage above and below.

Modular Offices

Modular 351 is a wood frame trailer that is used for offices and limited technician bench work. It had a Halon 1301 system in the space, but the agent cylinder(s) have been removed.

Modular 355 is protected with automatic sprinklers and contains electronic/mechanical shops and an office supporting the mission at the ATF.

5.1.1 Instrumentation and Data Processing Equipment

DOE/EP-0108 established levels of protection for Instrumentation and Data Processing equipment and the facility in which it is housed. The facility contains minimal computer equipment.

5.1.2 Vital and Important Records Storage

Vital records are those records which are essential to the mission of an important program and which, if lost, could not be reproduced or obtained elsewhere. Important records are those records possessing a high value to the mission of an important program but which, if lost, could be reproduced or reconstructed with difficulty or significant extra expense.

Based on the above definitions, there appear to be vital or important records in the building.

5.1.3 Trailers and Portable Structures

There are two modular structures associated with the facility. Refer to Section 6.1.

5.1.4 Cooling Towers

There are no cooling towers that expose the building.

5.1.5 Electrical Substations

There are no electrical substations associated with Building 820. Thirty-five feet to the west from Building 820 and 10-feet from Building 355 there are two oil filled transformers that have a 10-foot block wall separating them. Only one is identified; 820-TRNF-100, 603-1-11. The name plate data shows the following on the larger transformer:

- 13,200 volts, 3-phase, 500 KVA, 394 gallons of oil

5.1.6 Flammable Liquid & Gas Storage

The use of flammable liquids in Building 820 is generally well controlled, (refer to Section 6.1). The quantity of flammable gases and liquids in the facility is well less than the limits mandated by BCNYS Table 307.7(1) "*Maximum Allowable Quantity per Control Area of Hazardous Materials Posing a Physical Hazard*." Use of flammable liquids is in accordance with BNL ES&H Standards (found at https://sbms.bnl.gov/ld/ld08/ld08d481.pdf).

Building 820 has two full sized and one half sized flammable liquids cabinets in the main portion of the building.

5.1.7 Cables and Raceways

High voltage and low voltage, control, and signaling cables are well controlled throughout the building.

5.2 Unique Fire Hazards

There are no unique hazards in the building, other than described in Section 6.1.

5.3 Housekeeping in Vital Areas

Good housekeeping and control of combustibles was observed during this survey. The BNL Plan Review Process screens conventional construction operations.

5.4 Building Materials

There is no exposed polystyrene insulation installed on the HVAC ductwork and ceiling in Building 820.

5.5 Exterior Exposure Hazards

Any exterior structure, area or piece of equipment that is subject to harmful effects from, or can cause harmful effects to this facility is defined as an exterior exposure. Exterior exposures can be categorized as elements outside of the facility, and as components of the facility.

There are no significant exterior fire exposures to Buildings 820 and exposures consist of the following:

- To the North; None
- To the South; Open to tree line that's 125-feet
- To the East; 60-feet to trees at Building 820A
- To the West; None

5.6 Natural Phenomenon Hazard Exposure

Natural Hazards can be classified into five hazard categories: lightning, windstorm, wild fire, earthquake and flooding. The following is an evaluation for each category.

5.6.1 Lightning Potential

Based on NFPA standard 780 a lightning protection system is required. Refer to Appendix B that shows that the expected lightning frequency (Nd) is **0.0299** and the tolerable lightning frequency (Nc) is **0.0003**. Based on NFPA 780, If Nd > Nc, a lightning protection system should be installed **(See Recommendation HAI-09-820-01).**

5.6.2 Windstorm Potential

The Long Island area basic wind speed (3-second gust) is 120 MPH based on Factory Mutual Data Sheet 1-28 and BCNYS Figure 1609.4. The ground roughness exposure category for the area is 'Exposure B." Based on the calculations this building should have roof assemblies classified as "Class 90" rated assemblies.

5.6.3 Brush Fire Potential

Building 820 was not included in the "*BNL Wildland Fire Interface Survey Report*," dated August 2002.

An analysis was completed consistent with the requirements and guidelines of NFPA 1144 *Protection of Life and Property from Wildfire* (2002) to determine the wildfire risk to Building 820. The risk assessment was conducted in accordance with the Wildfire Hazard Severity Form checklist of NFPA 1144. The checklist is a summary of typical desirable characteristics found in various wildfire hazards analyses. Elements include emergency response ingress and egress, type of vegetation, topography, building construction and roofing materials, available fire protection, and utilities.

Based on the analysis, the hazard from wildfire to Building 820 is "Moderate" (score of 53), with 40 being the cut-off for low hazard. Specifics of the Wildfire Hazard Severity Analysis are shown in Appendix C of this report.

5.6.4 Earthquake Potential

The seismic damage potential for this facility is classified as low based on a Natural Hazards Analysis produced for the BNL campus titled "*DOE Accelerator Order 5820.25 Implementation*

Plan for Brookhaven National Laboratory National Phenomena Hazards Evaluation" dated April 1994. A low seismic classification means that the buildings and fire protection systems are not required to comply with seismic design standards.

5.6.5 Flooding Potential

Flood potential from bodies of water overflowing their normal levees is low for the BNL area. The flooding potential for this facility was classified as low in a Natural Hazards Analysis report produced for the BNL site, dated April 1994, titled "*DOE Accelerator Order 5820.25 Implementation Plan for Brookhaven National Laboratory National Phenomena Hazards Evaluation.*"

Groundwater runoff from a severe rainstorm could be a concern, but does not seem likely for Building 820 due to the surrounding terrain. Further evaluation is beyond the scope of this analysis.

5.7 Toxic Fire Potential

There are no known toxic materials present in the building that present a release potential due to fire. There were no identified PCB's within the building.

5.8 Biological Fire Potential

There are no known biological materials present in the building that present a release potential due to fire.

5.9 Radiation Fire Potential

There are known radiological materials present in the building that present a release potential due to fire, primarily from the accelerator.

6.0 PRE-FIRE AND EMERGENCY PLANNING

The BNL Fire Department maintains an adequate pre-fire plan book for this facility (http://intranet.bnl.gov/emergencyservices/runcards/main_i.asp). The pre-plan was reviewed as part of this analysis. The current version of the pre-plan is May 19. 2008.

6.1 Protection of Essential Safety Class Systems

There are no essential safety class systems associated with this non-nuclear facility.

6.2 Protection of Vital Programs

The operations associated with this facility are not considered to be a DOE vital program. Special fire protection precautions, beyond those that are described in this report, are not required for this facility.

6.3 Protection of High Value Property

High value equipment is generally regarded as any single item that is valued at $1 million or more, or where the loss of a single item could result in a loss of program continuity of greater than six months.

The following equipment within the building exceeds the $1M criterion:

- The linear accelerator in Building 820
- The equipment within the Experimental Hall, including the lasers
- The laser labs may meet this criteria, especially the YAG laser

6.4 Critical Process Equipment

By DOE standards, critical process equipment is considered to be equipment which, if lost or damaged in a fire, could delay a significant component of a major program for a period in excess of 6 months.

There is no such equipment within this building.

6.5 Maximum Possible Fire Loss (MPFL) and Maximum Credible Fire Loss (MCFL)

The MPFL, as defined in DOE Order 420.1, is the value of property within a fire area, unless a fire hazard analysis demonstrates a lesser (or greater) loss potential, assuming the failure of both automatic fire suppression systems and manual firefighting efforts. The fire loss estimate includes the replacement cost of equipment and property and any applicable decontamination and cleanup costs.

In accordance with the BNL Fire Safety Program, protection is required for facilities having an MPFL in excess of established thresholds as follows:

- When the MPFL exceeds $1 million an automatic sprinkler system designed in accordance with applicable NFPA standards is required;
- When the MPFL exceeds $25 million, a redundant fire protection system is required such that, despite the failure of the primary fire protection system, the loss will be limited to $25 million; and
- When the MPFL exceeds $50 million, a redundant fire protection system and a 3-hour fire resistance rated barrier are required to limit the MPFL to $50 million.

6.5.1 MPFL Scenario

The values within the building are generally well distributed throughout the building.

Combustible loading throughout the offices could be sufficient to potentially reach flashover conditions for heat release rates and fire duration, in light of the nature of the fuel loading associated with laboratories or transient combustibles.

Flashover indicates that the temperature inside these limited areas would be sufficiently hot to cause multiple fuel package ignitions within the space and result in loss of all contents. Associated compartment temperatures at flashover are generally accepted to be between 500°C (900°F) to 600°C (1100°F). Flashover is generally defined as the transition from a growing fire to a fully developed fire. Fully developed fires impose extensive thermal and physical stresses on fire barriers, the failure of which could lead to fire spread throughout the area.

6.5.2 MPFL Calculation

Building 820 has a replacement value of approximately $13 million ($12,309,430). The building value was obtained from 2004 replacement costs.

The average dollar density of building 820 is the replacement value divided by the floor area of the building $12,309,430/29,507 ft^2 = $417/$ft^2$.

The content and equipment value is calculated based on the following assumptions:

- An average of $20/$ft^2$ for content and equipment value within predominantly office areas, which does not apply to Building 820.
- An average of $100/$ft^2$ for content and equipment value within the industrial areas of the building.

A single MPFL fire is likely to cause severe damage to the entire building, due to the limited automatic sprinkler protection and also assuming no fire department response.

MPFL Summary

Attribute	Value
Building and contents	$13,000,000
MPFL Total	$13,000,000

6.5.3 MCFL Scenario

The MCFL, as defined in DOE Standard 1066-99 Fire Protection Criteria, is the value of property within a fire area, unless a fire hazard analysis demonstrates a lesser (or greater) loss potential. This assumes that all installed fire protection systems function as designed, and the effect of emergency response is omitted except for post-fire actions.

A single MCFL fire is assumed to cause significant damage prior to fire department response. This fire will be detected by the fire alarm system or the automatic sprinkler system for limited areas, but due to the general lack of automatic sprinklers, the MCFL fire will equal the MPFL fire.

MCFL Summary – Sprinklered Building

Attribute	Value
Building Value	$13,000,000
Contents	Included in the above
MCFL Total	$12,000,000

6.5.4 MPFL/MCFL Summary

Fire Area	MPFL	MCFL
Building 820	$13,000,000	$13,000,000

The MCFL figure is not within the criteria within the DOE Orders, and the BNL fire protection program criteria, refer to **Recommendation HAI-09-820-02**.

6.6 Recovery Potential

Critical process parts are those items essential to the operations of the facility that require a long lead-time for replacement. There is no equipment within the building that meets this criterion.

6.7 BNL Fire/Rescue Group

The BNL Fire/Rescue Group is a full time, paid department. Minimum staffing is five firefighters and one officer per shift. The firefighters are trained to meet Firefighter Level III by International Fire Service Training Association standard, National Fire Protection Association (NFPA) Fire Fighter Level II standard, and (NFPA) Hazardous Material Technician Level and they are Suffolk County Certified Confined Space Rescuers.

The BNL Fire/Rescue Group also provides emergency medical services to an on-site population of 3200 people. A minimum of two members per shift hold New York State "Emergency Medical Technician - D" certifications ("D" is for defibrillation). Normally all five firefighters have EMT status. The Group operates a New York State Certified Basic Life Support ambulance. Medivac services are available to BNL via the Suffolk County Police Department. Additionally the Fire/Rescue Group has two 1500 GPM "Class A" Pumpers, one Rescue Vehicle for initial hazardous material incident response and heavy rescue operation, and one Incident Command Vehicle.

The single Fire Station is located on the west side of the BNL Site. Response time to the most remote section of the BNL Site is less than eight minutes. Response time to Building 820 is estimated at 5 minutes or less.

BNL participates in the Suffolk County Mutual Aid Agreement. This allows the resources from over 130 departments to assist BNL. BNL is also a member of the Town of Brookhaven Foam Bank. BNL has a mutual aid agreement for hazardous material incidents with the Town of Brookhaven and Stonybrook University.

6.8 Fire Apparatus Accessibility

Fire apparatus accessibility is adequate for the facility. Current parking lot configurations allow access by apparatus in the event of an emergency.

6.9 Security Considerations Related to Fire Protection

The facility has limited security measures that restrict access (electronically locked doors). Provisions have been made for Fire/Rescue access via provision of master keys.

7.0 LIFE SAFETY CONSIDERATIONS

Life safety considerations for this facility include means of egress consisting of exit access, exits and exit discharge, exit signage, and emergency lighting. This building is required to comply with the state building code and NFPA 101®, the Life Safety Code (LSC). The requirements of both the 2007 edition of the Building Code of New York State (BCNYS) and the 2009 edition of the LSC have been applied to this analysis. It should be noted that the BCNYS is not intended to apply to existing structures. Appendix K of the BCNYS addresses alterations to existing structures.

7.1 Occupancy Load Factor and Calculations

Occupancy load factor and calculations

The following table summarizes the occupant load calculations based on both the BCNYS Table 1003.2.2.2 and NFPA 101 Table 7.3.1.2. An occupant load factor of 100 square feet for the Business occupancy was used for the entire building.

Table 8.1-1
Occupant Load Calculation

Location	**Occupancy Load Factor (per person)**		**Area (feet)**	**Occupant Load Calculations**	
	BCNYS	NFPA		BCNYS	NFPA
Building 820	100 gross	100 gross	29,507	296	296
		TOTAL	29,507	296	296

The total building occupant load for code compliance purposes is 296 occupants based on the BCNYS and NFPA 101 for the building. This occupant load exceeds the probable actual number of occupants. The building is occupied routinely throughout the day by generally less than 80 personnel.

7.2 Means of Egress

The means of egress for the building meets the present code requirements for number and arrangement of exits, capacity of exits, travel distance, common path of travel, dead ends, and security considerations related to egress, except as discussed previously. The following subsections discuss each of the elements.

One specific life safety recommendations has been submitted as a result of the walk down of the building.

7.2.1 Number and Arrangement of Exits

The LSC requires that a floor with an occupant load of 500 or fewer persons must have a minimum of two means of egress [§7.4.1.1]. Additional exits may be required for compliance with exit capacity or arrangement of exits criteria.

The building has sufficient exits to the exterior of the building. Exits are as follows:

- First Floor;
    - North: 1 from 820A into 820M, 1 for 820, 0 for 820M and 0 for the CO2 Lasers
    - South: 1 for 820 and 2 for 820A
    - East: 0 for 820A and 820
    - West: 5 for 820

7.2.2 Capacity of Exits

The egress capacity provided from a floor or portion thereof must be sufficient to accommodate the occupant load. The egress capacity for an egress component is based on the width of the component. For stairways, the factor of 0.3 in. of stair width per person is applied. For doors, ramps, corridors, and other level components, the factor of 0.2 in. of width per person is applied, per Table 7.3.3.1 of the Life Safety Code.

Street floor exits (i.e., First Floor) must be sufficient for the occupant load of the street floor plus the required capacity of stairs discharging through the street floor [LSC §39.2.3.3]. The building meets this criterion.

The available exit capacity of Building 820 exceeds the occupant load based on the BCNYS (Table 1003.2.3) and NFPA 101 (Table 7.3.3.1) for stairways and other egress components in this sprinklered building.

7.2.3 Travel Distance

Building 820 egress paths do not exceed the BCNYS and NFPA 101 travel distance limitations. BCNYS (Table 1016.1) limits egress travel distance to 300 feet in this type of

sprinklered Business occupancy. Since the building is sprinklered §39.2.6.2 of the Life Safety Code permits a travel distance of 300-feet for the building.

7.2.4 Dead-end corridors and Common Path of Travel

The building meets the dead-end corridor and common path of travel criteria found in the Life Safety Code. The criterion within the LSC is as follows:

Dead-end corridors:

Business, sprinklered and unsprinklered (§39.2.5.2)	50 feet

Common path of travel:

Business, sprinklered (§39.2.5.3.1)	100 feet

7.2.5 Security Considerations Related to Fire Protection

The buildings do not have special access controls that restrict egress or fire rescue ingress.

7.2.6 Separation of Means of Egress

Where exits or exit access doors are required, they must be located at a distance from one another not less than one-third the length of the maximum overall diagonal dimension of the building or area served [LSC §7.5.1.3.3] in buildings protected throughout by an approved automatic sprinkler system. The building is provided with primary exits that meet these criteria.

7.3 Exit Signs and Emergency Lighting

Exit signage is required in accordance with Section 7.10 of the LSC. Exit signs should be placed in corridors and in rooms required to have at least two means of egress. Internally-illuminated exit signs/frog eyes and exit placards are provided in the building.

Emergency lighting for means of egress is not required in accordance with §7.9 of the LSC because the building is only a single story in height with a total occupant load of 291 persons. Emergency lighting is required in business occupancies [§39.2.9] where the building is two or more stories in height above the level of exit discharge, the occupancy is subject to 100 or more occupants above or below the level of exit discharge, or the occupancy is subject to 1000 or more total occupants. However, emergency lighting is provided via “frog-eyes” in most locations.

7.4 Emergency Roof Exits

None.

7.5 Egress through Adjoining/Intervening Spaces

Exit access from rooms or spaces is permitted to be through adjoining or intervening rooms or areas, provided that such rooms or areas are accessory to the area served and the intervening

rooms or areas are not spaces identified under Protection from Hazards (e.g., storage rooms) [LSC §7.5.1.6]. The building complies with this criterion.

7.6 Exit Discharge

Exits are required to terminate directly at a public way or at an exterior exit discharge. The LSC permits a maximum of 50 percent of the required number of exits to discharge inside the building provided the level of discharge is fully-sprinklered or the area of discharge is sprinklered and separated from the remainder of the building by fire barriers [§7.7.2.2; §7.7.2.4]. All exits for Building 820 exit to a public way.

7.7 Horizontal Sliding Doors

Approved, existing horizontal-sliding or vertical-rolling fire doors are permitted in means of egress under the following conditions [LSC §40.2.2.2.4]:

- They are held open by fusible links.
- The fusible links are rated at not less than 165°F.
- The fusible links are located not more than 10 ft above the door.
- The fusible links are in immediate proximity to the door opening.
- The fusible links are not located above a ceiling.
- The door is not credited with providing any protection for life safety purposes (i.e., property protection only).

There are no such doors in this building.

7.8 Fire Escape Ladders

None

7.9 Door Heights

Means of egress are required to provide a headroom clearance of not less than 6 ft 8 in. at doorways [LSC §7.1.5.1]. The existing doors meet this requirement.

7.10 Discharge to Roofs

None

7.11 Barriers

7.11.1 Occupancy Separations

Occupancy separations are not required for Building 820 since there is a single occupancy for the building.

7.11.2 Incidental Use Areas

Incidental use areas or hazardous areas are considered those spaces that pose a relatively higher hazard than the predominant occupancy of the area in which they are located. Such spaces are not necessarily classified as high-hazard (Group H) occupancies. Hazardous areas include general storage rooms, boiler or furnace rooms, and maintenance shops. The LSC requires hazardous areas to be separated from adjoining areas by a 1-hour fire resistance-rated barrier without windows or protected by automatic fire suppression systems [LSC §8.7.1.1]. Rooms with severe hazards such as maintenance shops with woodworking and painting are required to have both fire barrier enclosure and automatic fire suppression.

There are limited rooms with incidental use associated with Building 820, and these consist of utility support areas.

7.11.3 Separation of Means of Egress

The exits within the building are separated and meet the separation criteria within NFPA 101.

7.11.4 Exit Access Corridors

Exit access corridor walls are typically constructed of concrete masonry and extend from the floor to the underside of the floor slab above. Fire resistance-rated corridor walls are not required in existing industrial occupancies [LSC §40.3.6].

The BCNYS requires exit access corridors serving a Group B occupancy in non- or partially-sprinklered buildings to be enclosed with 1-hour fire partitions [BCNYS Table 1004.3.2.1]. This does not apply to this building.

There are no exit access corridors in Building 820 thus this criterion does not apply.

7.11.5 Vertical Opening Barriers

Refer to §8.2.1 for the details on the stairwells and vertical openings in the building.

7.11.6 Egress Stairways

Vertical openings, including stairways, are required to be enclosed with fire-resistive construction to limit fire and smoke spread to other floors, per §7.2.2.5.

Vertical openings must be enclosed or protected in accordance with LSC Section §8.6 unless otherwise permitted by the following [§39.3.1]:

1. Unenclosed vertical openings in accordance with 8.6.8.2 shall be permitted.
2. Exit access stairs shall be permitted to be unenclosed in two-story, single-tenant spaces that are provided with a single exit in accordance with §39.2.4.2(5).
3. Unprotected vertical openings shall be permitted in buildings complying with all of the following:

a. Where protected throughout by an approved automatic sprinkler system in accordance with §9.7.1.1(1);

b. Where no unprotected vertical opening serves as any part of any required means of egress; and

c. Where required exits consist of exit doors that discharge directly to grade in accordance with §7.2.1, outside stairs in accordance with §7.2.2, smokeproof enclosures in accordance with §7.2.3, or horizontal exits in accordance with §7.2.4.

7.12 Fire Protection Systems Required by Code

Automatic sprinkler protection is not required to address life safety conditions found in the building.

7.13 Operational Requirements that are Required by Code

When performed, cutting and welding operations in the building are required to be conducted in accordance with NFPA 51B**,** *Standard for Fire Prevention during Welding, Cutting, and Other Hot Work*, 2003 Edition.

There are no other fire protection related operational requirements required by code.

8.0 REFERENCE DOCUMENTS

8.1 National Fire Protection Association

NFPA 10, *Standard for Portable Fire Extinguishers*, 2002 Edition

NFPA 13, *Standard for the Installation of Sprinkler Systems*, 2007 Edition

NFPA 30, *Flammable and Combustible Liquids Code*, 2008 Edition

NFPA 51B**,** *Standard for Fire Prevention during Welding, Cutting, and Other Hot Work*, 2009 Edition

NFPA 70, *National Electrical Code*®, 2008 Edition

NFPA 72®, *National Fire Alarm Code*®, 2007 Edition

NFPA 101®, *Life Safety Code*®, 2006 Edition

NFPA 220, Standard on *Types of Building Construction*, 2006 Edition

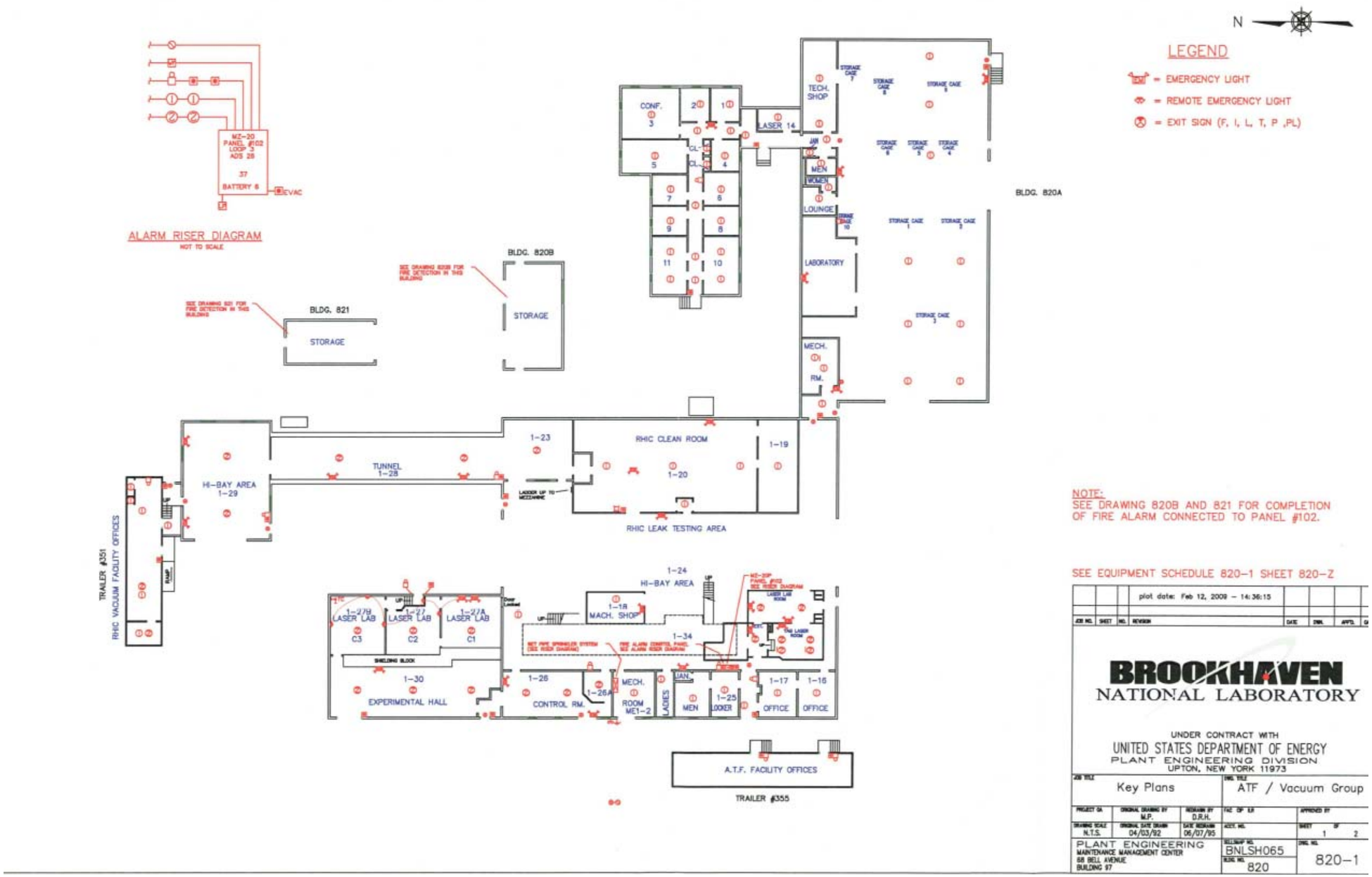
NFPA 780, *Standard for the Installation of Lightning Protection Systems*, 2004 Edition

NFPA 1144, *Standard for Protection of Life and Property from Wildfire*, 2002 Edition

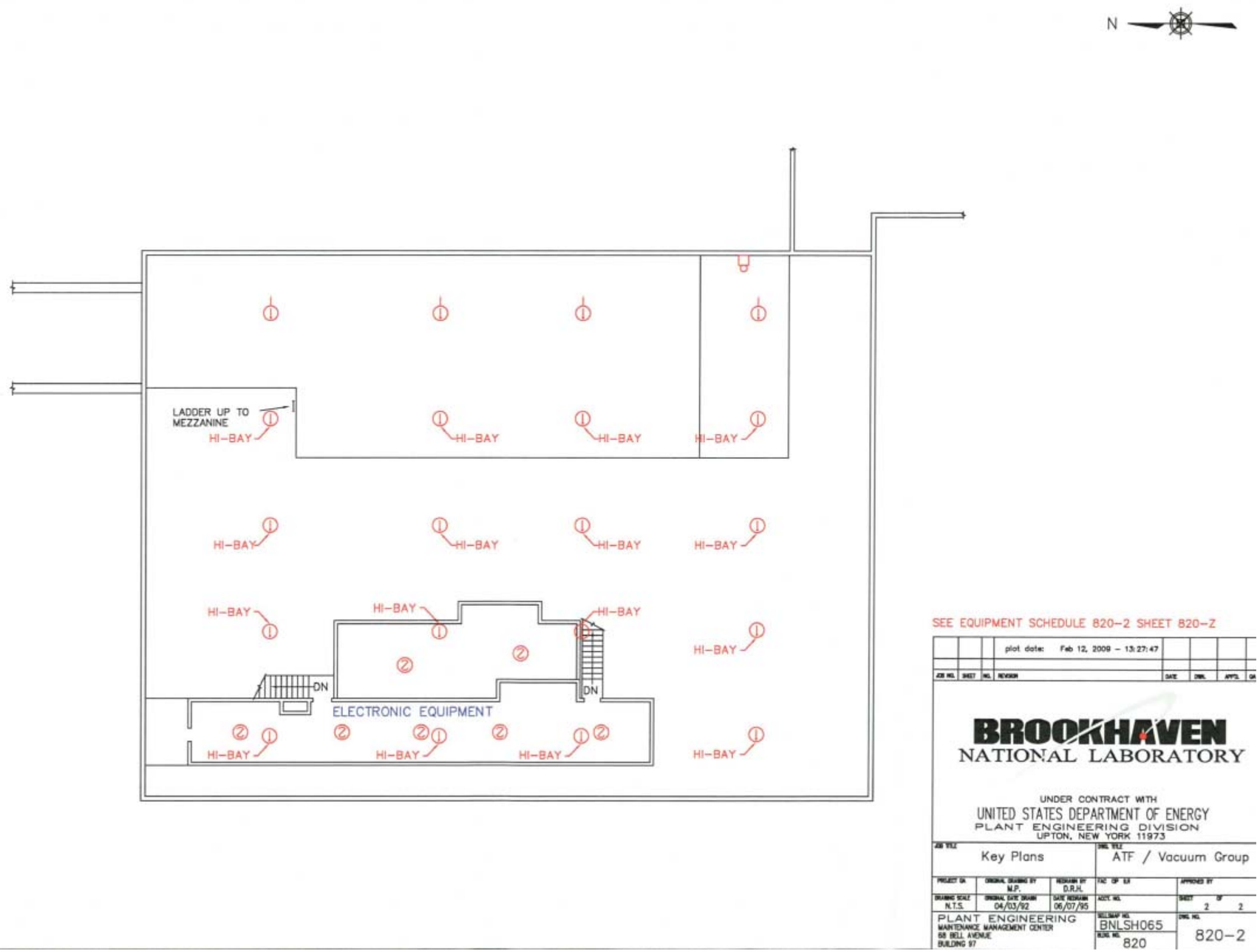
8.2 FM Global Loss Prevention Data Sheets

None.

APPENDIX A – FHA FIGURERS



Building 820 – First Floor



Building 820 – Mezzanine

APPENDIX B –

LIGHTNING RISK CALCULATION

The expected lightning frequency (Nd) is **0.0158** and the tolerable lightning frequency (Nc) is **0.0006.** Based on NFPA 780, If Nd > Nc, a lightning protection system should be installed.

Lightning Protection Calculation - Building 820

9/10/2009

EXPECTED LIGHTNING STROKE FREQUENCY FROM NFPA 780 2006 APPENDIX L

$$N_d = (N_g)(A_e)(C_1)$$

N_d = **0.0299** = yearly average flash density in the region where the structure is located

(N_g) = **2.0** = the yearly lightning strike frequency to the structure

(C_1) = **0.50** = the environmental coefficient

(A_e) = **0.02985203** = the equivalent collective area of the structure in km2 from calculation below

Length (L)	**300**	Feet
Width (W)	**169**	Feet
Height (H)	**60**	Feet

Figure H.4.2(a) Results 0.02985203 sq. km

Figure H.4.2(b) Results 0.00945610 sq. km

Figure L.4.1(a) Calculation of the equivalent collective area for a rectangular structure.

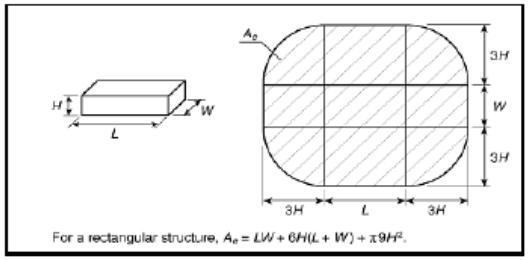


Figure L.4.1(b) Calculation of the equivalent collective area for a structure where a prominent part encompasses all portions of the lower part of the structure.

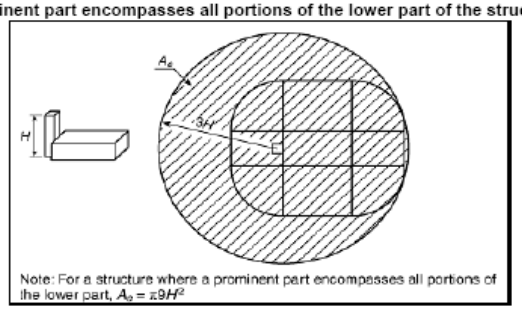


Table L.4.3 Determination of Environmental Coefficient C_1

Assume	Relative Structure Location	C_1
0.50	Structure located within a space containing structures or trees of the same height or taller within a distance of $3H$	0.25
	Structure surrounded by smaller structures within a distance of $3H$	0.5
	Isolated structure, no other structures located within a distance of $3H$	1
	Isolated structure on a hilltop	2

= input required

Lightning Risk Calculation

Lightning Protection Calculation - Building 820

9/10/2009

TOLERABLE LIGHTNING FREQUENCY FROM NFPA 780 2006 APPENDIX L

N_c = **0.0003**

$$N_c = \frac{1.5 \times 10^{-3}}{C}$$

where $C = (C_2)(C_3)(C_4)(C_5)$.

Assume **0.5**

C_2 — Structural Coefficients			
		Roof	
Structure	Metal	Nonmetallic	Flammable
Metal	0.5	1.0	2.0
Nonmetallic	1.0	1.0	2.5
Flammable	2.0	2.5	3.0

Assume **2.0**

Structure Contents	C_3
Low value and nonflammable	0.5
Standard value and nonflammable	1.0
High value, moderate flammability	2.0
Exceptional value, flammable, computer or electronics	3.0
Exceptional value, irreplaceable cultural items	4.0

Assume **1.0**

Structure Occupancy	C_4
Unoccupied	0.5
Normally Occupied	1.0
Difficult to evacuate or risk of panic	3.0

Assume **5.0**

Lightning Consequence	C_5
Continuity of facility services not required, no environmental impact	1.0
Continuity of facility services required, no environmental impact	5.0
Consequences to the environment	10.0

= input required

Lightning Protection Calculation - Building 820

9/10/2009

The expected lightning frequency (**Nd**) is **0.0299**

The tolerable lightning frequency (**Nc**) is **0.0003**

Based on NFPA 780, If Nd > Nc, a Lightning Protection System shall be installed.

APPENDIX C – Determination of Wildfire Hazard Severity

Using NFPA 1144

WILDLAND FIRE RISK AND HAZARD SEVERITY ASSESSMENT FORM
Appendix A, Figure A.4.2 from NFPA 1144

ELEMENT	POINTS
A. Means of Access	
1. Ingress and egress	
a. Two or more roads in/out	**0**√
b. One road in/out	7
2. Road width	
a. >= 24 ft	0
b. >= 20 ft and < 24 ft	**2**√
c. < 20 ft	4
3. All-season road condition	
a. Surfaced road, grade <5%	**0**√
b. Surfaced road, grade > 5%	2
c. Non-surface road, grade < 5%	2
d. Non-surface road, grade > 5%	5
e. Other than all-season	7
4. Fire Service Access	
a. <= 300 ft with turnaround	**0**√
b. > 300 ft with turnaround	2
c. < 300 ft with no turnaround	4
d. >= 300 ft with no turnaround	5
5. Street Signs	
a. Present	**0**√
b. Not present	5
B. Vegetation (Fuel Models)	
1. Characteristics of predominate vegetation within 300 ft.	
a. Light (e.g., grasses, forbs, sawgrassess, and tundra) NFDRS Fuel Models A,C,L,N,S, and T	5
b. Medium (e.g. light brush and small trees) NFDRS Fuel Models D,E,F,H,P,Q, and U	**10**√
c. Heavy (e.g. dense brush, timber, and hardwoods) NFDRS Fuel Models B,G, and O	20
d. Slash (e.g. timber harvesting residue) NFDRS Fuel Models J,K, and L	25
2. Defensible space	
a. More than 100 ft of vegetation treatment from the structures	1
b. 71 ft to 100 ft of vegetation treatment from the structures	3
c. 30 ft to 70 ft of vegetation treatment from the structures	**10**√
d. < 30 ft of vegetation treatment from the structures	25

C. Topography Within 300 of Structures

1.	Slope < 9%	**1**√
2.	Slope 10% to 20 %	4
3.	Slope 21% to 30%	7
4.	Slope 31% to 40%	8
5.	Slope > 41%	10

D. Additional Rating Factors

1.	Topographical features that adversely affect wildland fire behavior	0-5 [**0**√]
2.	Areas with a history of higher fire occurrence than surrounding areas due to special situations	0-5 [**0**√]
3.	Areas that are periodically exposed to unusually severe fire weather and strong dry winds.	0-5 [**0**√]
4.	Separation of adjacent structures that can contribute to fire spread	0-5 [**0**√]

E. Roofing Assembly

1.	Class A roof	0
2.	Class B roof	3
3.	Class C roof	15
4.	Nonrated	**25**√

F. Building Construction

1.	Materials		
	a.	Noncombustible/fire-resistive siding, eaves, and deck	**0**√
	b.	Noncombustible/fire-resistive siding and combustible deck	5
	c.	Combustible siding and deck	10
2.	Building setback relative to slopes of 30% or more		
	a.	>= 30 ft to slope	1√
	b.	< 30 ft to slope	5

G. Available Fire Protection

1.	Water source availability		
	a.	Pressurized water source availability	
		500 gpm hydrants <= 1000ft apart	**0**√
		250 gpm hydrants <= 1000ft apart	1
	b.	Nonpressurized water source availability	
		>= 250 gpm continuous for 2 hours	3
		< 250 gpm continuous for 2 hours	5
	c.	Water unavailable	10
2.	Organized response resources		
	a.	Station <= 5 miles from structure	**1**√
	b.	Station > 5 miles from structure	3

3.	Fixed fire protection	
	a. NFPA 13	0
	b. None	5
	c. Partial	**3**√
H.	**Placement of Gas and Electric Utilities**	
1.	Both underground	**0**√
2.	One underground, one aboveground	3
3.	Both aboveground	5
I.	**Total**	**53**

Hazard Assessment	Total Points
Low hazard	**< 40**
Moderate hazard	40-69
High hazard	70-112
Extreme hazard	> 112

A Wildfire Severity Level of 53 = A **Moderate** Hazard

Appendix II

Life Safety Code Analysis
Brookhaven National Laboratory
Building 820, Accelerator Test Facility

Prepared by: J. A. Eckroth

Reviewed by: J. W. Levesque

Date of Survey: October 3, 1997
Updated: February 3, 1999

Date of Report: October 29, 1997
Updated: February 3, 1999

Conferred with: N. Gmur, Environment, Safety and Health Coordinator, NSLS
B. Cahill, Point of Contact at Building 820

Scope

This is an analysis of the level of life safety (i.e.: the ability of occupants to exit during a fire) and compliance with the Life Safety Code (LSC)[1]. The analysis of Bldg. 820 in this report is limited to those areas of Bldg. 820 occupied by the Accelerator Test Facility (ATF). Compliance with the Life Safety Code is one of the performance objectives of DOE Order 420.1[2].

Summary

The uses of the building, as described under "Occupancy", below, are based on a field survey and on discussions with N. Gmur and B. Cahill. The building complies with most aspects of the LSC and is acceptable for continued occupancy.

Recommendations

There are no new recommendations as a result of this updated survey. All recommendations made on previous surveys have been closed out.

Analysis

Building Construction

The ATF portion of Building 820 is a one story building with a mezzanine and is of insulated metal panel and steel frame construction. Interior walls are a combination of concrete block, gypsum *board on wood and steel studs, and metal and composite panels.*

A building layout is shown on the diagram in Attachment 1.

Fire Protection

The ATF area of Building 820 is protected with a combination of automatic sprinklers, fixed temperature/rate of rise heat detectors, smoke detectors, and manual fire alarms. Alarms are arranged to annunciate: locally, at BNL Fire/Rescue Headquarters (Building 599), and at BNL Police Headquarters (Building 50).

---

[1] *National Fire Protection Association No. 101, Life Safety Code, 1994 Edition*

[2] US Department of Energy Order No. 420.1, Facility Safety, 10/13/95

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[1]*National Fire Protection Association No. 101, Life Safety Code, 1994 Edition*

[2]US Department of Energy Order No. 420.1, Facility Safety, 10/13/95

Classification of Occupancy

The overall occupancy classification of the ATF area of Building 820 for LSC purposes is General Industrial. The offices and control room located within Bldg. 820 are incidental to the main occupancy. No high hazard operations are associated with the ATF areas in Building 820.

Occupant Load

The ATF facility including the mezzanine and trailers covers approximately 8400 sq. ft. of floor area. Based on an occupancy load factor of 100 sq. ft./ person, the entire occupancy load for this area of Bldg. 820 is 84 people. This occupancy load is for LSC analysis and does not necessarily reflect the actual occupancy load of the building which under normal conditions is expected to be less.

Means of Egress Components

The doors in Bldg. 820 provide for an adequate means of egress in accordance with the LSC. In addition, most of the stairs in Bldg. 820 comply with the requirements of either Class A or Class B stairs as allowed by the LSC for an existing facility.

The landing on the Laser Room side of the 36 inch exit access door into the new YAG Laser Room is 43.5 inches wide by 25 inches deep. In addition, the width of the two steps in the Laser Room are only 25 inches. The LSC normally requires a landing equal to the width of the door on both sides of the door and the width of the stairs to be 36 inches. The current arrangement of this landing and the steps is considered tolerable because of the limited use of the door, landing, and steps into the Laser Room.

The second means of egress from the mezzanine area is via alternating tread device. The use of this device as a secondary means of egress from the mezzanine is tolerable because the mezzanine is not a normally occupied space. When the mezzanine is occupied, it is not occupied by more than three persons and all occupants are capable of using the alternating tread device.

There are no ramps, horizontal exits, exit passageways, fire escape stairs, or fire escape ladders serving this building.

Capacity of Means of Egress

Exit capacity is based on the calculated occupancy load and on exit width factors, such as 0.2 inches/person for horizontal components and 0.3 inches/person for stairs. With the exception of the one item noted below, there is adequate exit width from the ATF area of Building 820 and from each area within the building to accommodate the calculated occupancy load.

The minimum width of all means of egress in an industrial occupancy, including exit egress width, should be no less than 28 in (LSC 5-3.4.1). There is one location in the ATF areas of Bldg. 820 where the exit egress width is reduced to less than 28 in. The location is in the Experimental Area of the ATF where a survey pole is periodically placed in the egress path to allow alignment of the beamlines in this area. It was indicated by facility personnel that the survey pole is only installed when surveys are taking place and is removed when not in use. This incidental obstruction to the egress path during limited time periods while surveys are being performed is considered tolerable.

LSC, Building 820, Page 3

Number and Arrangement of Means of Egress

All ATF areas of Building 820 are provided with an adequate number of properly arranged exits. Common paths of travel and dead end corridors are within the 50 ft. maximum LSC allowance.

Travel Distances to Exits

Total travel distance to an exit from all ATF areas of Building 820 are within the 200 ft. LSC limitations for General Industrial occupancies.

Discharge from Exits

All required exits in the ATF area of Building 820 discharge directly to a public way or at an exit discharge.

Emergency Lighting and Marking of Means of Egress

Adequate emergency lighting is provided in the exit access areas of Building 820. The required means of egress for this facility are adequately marked.

Protection of Vertical Openings

There are no vertical openings in this one story building.

LSC, Building 820, Attachment 1
Page 1 of 1

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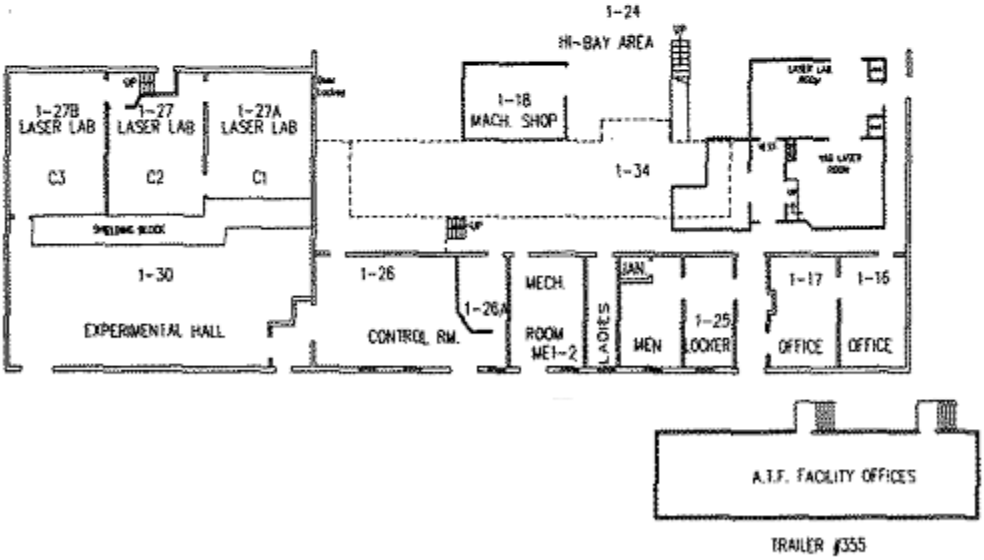

Not to Scale

Appendix III

Radiation Dose Rates From Gamma Radiation and Neutrons

III.1 Beam Loss Near a Focusing Quadrupole

In general terms the beam size is largest in one or other of the horizontal and vertical directions in the region of a quadrupole triplet. We will first consider a 1 % beam loss in the region of the first quadrupole triplet following the accelerating sections. (A similar situation will be present at subsequent quadrupole triplets). Electrons will only strike the beam pipe at an angle of less than 1 degree so they will pass through ~9.5cm of the 0.064inch thick, stainless steel, beam pipe. From Figure 1a, we can see that, for normal setting of the quadrupole triplet, the beam size is largest just past the end of the third quadrupole of the triplet so that any electron losses will occur in that region. Assuming a density for stainless steel of 7.87 gm/cc we obtain an equivalent thickness of 74.77 gm/cm^2. The average rate of energy loss <dE/dx> =11.8 MeV / gm/cm^2 so electrons hitting the wall at this angle would be stopped there. The range of 120MeV electrons in matter is ~ 80gm/cm^2 so the stopping distance in iron (or steel) is ~6.78 cm. Therefore, all of the electrons striking the beam pipe would produce gamma rays near the exit of the third quadrupole of the triplet. The gammas produced in the transverse direction will be somewhat shielded by the iron yoke of the quadrupole, or the steel flanges of the beam pipe. We may estimate the level of radiation at the point where these gammas would strike the yoke from a knowledge of the equivalent average current. The total average current in the electron beam, in multi-bunch mode, at a repetition frequency of 6 Hz, is 600nA and, assuming conservatively that 1% of this strikes the beam pipe, we obtain an equivalent current for the lost electrons of 6nA. (Note that for normal operation in single bunch mode at 6Hz the total average current in the beam is 6nA) We obtain the gamma emission rate at 90 degrees to the beam direction, in terms of absorbed dose index rate, at a reference distance of 1 m, from Appendix E of NCRP Report No. 51, as 5000 x I beam in mA or $3x10^{-3}$ rads m^2/min. for 120 MeV electrons stopped in heavy or light elements. The yoke of the quadrupole is ~9.5 cm from the beam pipe and it is ~0.95cm thick. The rate at the yoke inner surface is 332 mrad/min, or 20 rad/hr. About 90% of this will pass through the steel yoke where it will be attenuated and eventually strike the concrete wall of the accelerator tunnel (the steel flanges of the beam pipe are thicker than the quadrupole yoke and will give better shielding). The nearest tunnel concrete wall on the control room side is ~ 0.3m from the gamma source and the radiation level at that point, after attenuation by the steel of the magnet yoke, is ~1.8 rad/hr. The 1.15m concrete wall will reduce this by a factor of $5x10^{-3}$ so that the level outside the concrete shield wall would be 9mrad/hr. On the high bay side the inner surface of the concrete wall is 0.5m from the source but the concrete wall there has an equivalent thickness of 1m. The level outside the wall there is calculated to be 13 mrad/hr. The inside surface of the tunnel roof is also 0.3m from the source and the concrete thickness is 1m so the level immediately outside the roof is 36 mrad/hr. The forward gammas which are more intense by about three orders of magnitude, and 90% of which are contained within an angle of 15 degrees, would travel some distance before hitting vacuum pipe flanges and the steel and or copper of subsequent beam line elements However, there is ample room to place a lead shield wall around the beam pipe at the nearest convenient location after the quadrupole triplet. A wall of lead extending 12 inches from the center of the beam line and 8 inches in length would provide sufficient shielding to reduce the radiation dose outside the shield wall to negligible levels. Beam losses at other quadrupole triplets

along the H-line would result in the same level of radiation. Note that there are no plans to operate the ATF at 6Hz and with 100 beam bunches of 1nC charge for any currently approved experiments. Operation has been conducted at ~10 beam bunches with <1nC charge per bunch at a repetition rate of 1.5 Hz. This would reduce the above rates by a factor of 40 (assuming the same 1% beam loss) giving manageable levels of <1 mrad/hr outside the shield wall. Operation for beam set up and studies at this maximum level would only be carried out, if at all, for an estimated 24 hours per year so, given the likely occupancy for a given region by any individual, the above levels are acceptable. The gamma rays striking the lead or concrete will produce photo neutrons and the shielding of these will be treated later in this document.

III.2 Loss Near a Dipole, Bending Magnet

There could be some electrons of energy lower than the design energy that make their way through the accelerating sections and up to the first dipole, bending magnet. These electrons would almost certainly be lost somewhere inside that magnet. We will assume that 1% of the beam is lost at some point inside the first dipole. Once again it is likely that the electrons will have energies close enough to those in the main beam that they will strike the beam pipe almost tangentially and give up all of their energy to it. The source level will be the same as for the quadrupole case but the dipole steel poles are much thicker and therefore provide more shielding in the transverse direction. The level outside the shield wall should be an order of magnitude less than for the quadrupole case and can be considered to be negligible in terms of radiation dose from gamma radiation. The more intense forward directed gamma beam will ultimately strike the floor of the tunnel and be absorbed there without contributing to the dose outside of the accelerator tunnel. Missetting of subsequent dipoles could also give rise to beam losses but this can be considered an accidental beam loss and will be considered in a later section of this document. The residual beam loss in the first dipole when a beam profile monitor is inserted into the beam is considered later.

III.3 Beam Striking a Profile Monitor

During accelerating tuning or trouble shooting processes it is customary to introduce beam profile monitors into the electron beam in order to measure its position and size. These devices are typically made from a 0.25inch aluminum plate to the front surface of which is glued a coated glass plate, also 0.25 inches thick. These devices are set at an angle of 45 degrees to the direction of the electron beam and are viewed with a TV or CCD camera. They are not thick enough to stop the electron beam but will degrade the energy and also produce gamma rays. Electrons passing through these devices will continue along the beam line, albeit at lower energy, and will eventually strike the beam pipe at some location downstream thereby being stopped and producing more gamma rays. The range for 120 MeV electrons in glass or aluminum is 26.7 cm. So the electrons will readily pass through the profile monitor. The average energy loss of the electrons in passing through the 1.8 cm of glass and aluminum is 67 MeV (since $\langle dE/dx \rangle = 13.7$ MeV/g/cm^2). So electrons with an energy of 53 MeV will continue down the beam line. Those hitting the profile monitor just upstream of the first quadrupole triplet will be over focused by it since they are at the wrong energy for proper focusing. Since there will be scattering of the electrons by the profile monitor the beam size will also be larger so some electrons will be lost inside the first triplet. Others will continue on down the beam line

and into the first dipole bending magnet where they will be bent into the wall of the vacuum chamber and into the steel of the magnet poles where they will be stopped. The full 600nA beam hitting the profile monitor will produce only a fraction of the total number of gammas produced by stopping the electron beam. Most of the gammas will be produced when the beam is stopped inside the first dipole
magnet.

If all of the 120 MeV electrons were stopped at the profile monitor the emission rate at 90 degrees would be 5000 x 600 x 10^{-6} rads m^2 /min. If 53 MeV electrons were stopped the emission rate would be 4000 x 600 x 10^{-6} rads m^2 /min. Therefore, 80% of the gammas produced by the electrons passing through the profile monitor are produced where the 53MeV beam is stopped.

We estimate that the 20% of the gammas that are produced at the profile monitor will give rise to an emission rate from aluminum at 90 degrees of 1000 x 600 x 10^{-6} rads m^2 /min. or 0.6 rads m^2 / min. at 1m from the source. The radiation level at the inner surface of the tunnel wall on the high bay side that is 0.5m from the source will be 144 rads/hr. In passing through the 1m thick concrete wall this will be reduced by a factor of 15 x 10^{-3} to a level of 2.2 rads/hr. This level is unacceptable even for the short time, of the order of 1minute or less, that the individual profile monitor would be in place. A 4-inch thick lead wall around each profile monitor would reduce the level outside the shield wall by a factor of 100 or to 22 mrads/hr. The inner surface of the tunnel wall on the control room side is only 0.3m from the source but the concrete wall is 1.15m thick so the level outside the shield on that side, with 4 inches of lead shielding, will be 40 mrads/hr. The tunnel roof is 0.3m from the source and the concrete there is also 1.15m thick so the level just outside the roof is also 40 mrads/hr. Normally the ATF operates at 1.5 Hz and in single bunch mode where the average current is only 1.5nA. Under these conditions introduction of a profile monitor in the beam would result in negligible levels of ~ 100 μrads/hr outside the accelerator tunnel. A typical time for a given profile monitor to be in the beam is <1minute, so that, even when operating at the highest beam charge, the dose to a person right against the shield wall would be < 1mrad.

As stated earlier the bulk of the electron beam will be stopped in the steel of the dipole magnet and its beam chamber wall. The 53 MeV electrons will be bent downward directly into the chamber wall at a steep angle so they will pass through it and into the 1.5 inch thick steel pole piece. 53 MeV electrons are stopped by 4cm of steel so the remaining 1 cm will act as a partial shield for the gamma rays that are produced. For 53 MeV electrons stopped in steel the 90 degree emission rate at 1m is 4000 x (beam current in mA) rads m^2 /min, or1.8 rads m^2 /min. Gammas at 90 degrees from this source will see differing amounts of shielding material depending on the direction of travel. Those going downward will strike an aluminum support plate and then the floor of the accelerator tunnel. They will not contribute to gamma radiation levels outside of the tunnel. Those traveling upwards will strike the two walls of the vacuum chamber and then the 1.5 inch thick steel pole which is ~ 20 cm. from the source point. The tunnel roof is a further 30 cm. from the top of the magnet pole. Without taking account of the shielding provided by the steel magnet pole the level at the ceiling would be 9.6 rads/min or 576 rads/hr.1.5 inches of steel will reduce this to ~ 460 rads/hr. and the 1.15m concrete ceiling will reduce this to 4.7 rads/hr.

Six inches of lead above the dipole magnet gap region would reduce this to ~23 mrad/hr. This is an acceptable level since the time that any given monitor is in the beam is only a minute or

less. In the two horizontal directions there is 4.5 inches of steel shielding adjacent to the source of

gammas. This will attenuate the gammas by a factor of 10 directly opposite the point where the electron beam is stopped. The nearest wall, on the walkway side, is 30 cm from the source so the level at the inside surface there will be 160 rads/hr. The 1.15m thick wall will reduce this to 1.6 rads / hr. Four inches of lead will reduce this by a factor of 200 to a level of 8 mrad/hr. On the high bay side the tunnel wall is 60 cm from the source so the level there will be 40 rads/hr. The 1m thick concrete wall will reduce this to 600 mrad/hr and four inches of lead added will lower this to 0.7 mrad/hr. Forward directed gammas would strike the concrete floor of the accelerator tunnel and not contribute to radiation dose. The level of 23 mrem/hr. is rather high, even though it would only be present for short periods of time. However, our assumed maximum operating level for the average beam current is 40 times any presently planned operational situation and operation in that mode would only occur for 10% of the ATF operating time. It would be appropriate to introduce lead shielding if and when the ATF is set to operate at the maximum operating level and in the meantime to install a radiation monitor, with remote readout and an alarm, at the point where the maximum level of radiation could occur. Alternatively, the accelerator could be operated at reduced repetition rate for set up and testing at the highest current level.

III.4 Beam Striking a Profile Monitor and the Faraday Cup / Beam Stop Situated after the Third Dipole of the Chicane

During beam set up the fourth dipole of the chicane may be turned off to allow monitoring of the beam profile and charge in the straight ahead line after the third dipole of the chicane. The total number of hours for operation in this mode at the highest energy and with the highest total beam charge of 600nC will be very few maybe as little as 12 hours in a year. However, all of the beam charge will be stopped in the Faraday cup and we will calculate the gamma radiation production rate under this mode of operation. For a 120 MeV electron beam with a total current of 600 nA being stopped in an aluminum Faraday cup Appendix E of NCRP Report No.51 gives a gamma ray emission rate at zero degrees of 1800 rads m^2 / min. at a reference distance of 1m. The concrete roof of the tunnel is ~50 cm. From the source so the level there would be four times this rate or 7200 rads / min. (432000 rads/hr.) These forward gammas will strike the roof at an angle that will give rise to ~ 2.5 m of ordinary concrete shielding. This will reduce the radiation level by a factor of 100000 or to 4.32 rads/hr. 6 inches of lead shielding would reduce this by another factor of 500 to a level of 8.6 mrads/hr.

The emission rate at 90 degrees is 3.6 rads m^2 / min. at 1m. In this direction the roof is only ~ 20cm from the gamma source so the level at the roof is 30 rads/min or 1800 rads/hr. this would be reduced to 18 rads/hr. by the 1.15m thickness of concrete. Six inches of lead shielding would reduce this to 36mrads/hr. Remembering that the above maximum operational level is 40 times higher than any presently planned, and that even that mode of operation would be carried out for 10% or less of the ATF operating time, these levels are acceptable. Note also that operation of the ATF with beam being stopped in this particular Faraday cup would only occur during beam testing or set up which would be carried out for a short period of time. The likely dose to an individual situated at these locations would be less than 1mrem.

III.5 Radiation Dose From Neutrons

Wherever the gammas resulting from stopping electrons are attenuated in material neutrons are produced. In most cases we will be attenuating the gammas by the use of lead shielding and the shield will be the neutron source. In section 4.5.2.1 of the SAD for the ATF the neutron fluence at 2m

from the beam stop in the Experimental Area where the full beam is stopped was calculated to be $4x10^{11}$ neutrons/cm^2 year. This assumed operation at the full energy, maximum repetition rate, and maximum beam current for the entire year. The worst situation in the accelerator tunnel region would be operation with the above beam conditions into the Faraday cup/beam stop situated after the third dipole in the chicane. However, operations at that location would only occur for at most 1% of the annual operating time so the flux at 2m would be $4x10^9$ neutrons/cm^2 year. The concrete shielding of the tunnel roof is at the nearest point to the neutron source and is only 25cm from it. The flux in that region is therefore $2.6x10^{11}$ neutrons/cm^2 year.

To reduce this to 100mrem would require a reduction factor of $3.85x10^{-12}$ rem cm^2 to be applied to this fluence. This requires 240 g/cm^2 or 102 cm of ordinary concrete shielding. Operation at 1.5 Hz with 1nC charge in a single bunch for 200 hours per year into the Faraday cup/beam stop in the tunnel would give a neutron fluence of $6.4x10^9$ neutrons/cm^2 at 25cm from the source. This would require a reduction factor of $6.4x10^{-10}$ or 50 cm of ordinary concrete. The existing tunnel walls and roof are more than 1m thick and provide the necessary shielding for all anticipated operating conditions.

Appendix IV

Air Activation Calculations

During normal operation, no air activation of any sort will occur since:

(a) The beam is not exposed to air.

(b) No ozone is produced.

(c) No radionuclides are produced.

Most of the electron losses occur during the capture process in the first accelerating section, at energies below 15 MeV, which is the typical threshold energy for activation by electrons. Thus, the only possibility for air activation is in the case of a failure of a magnet power supply causing the high energy (>15 MeV) electron beam to exit through the vacuum chamber, or activation of the electron beam dump. We calculate below the activation products for these situations.

Even without forced ventilation a complete air change usually occurs a few times per hour. Therefore, it is not possible to reach saturation levels for ^{3}H or ^{7}Be or approach the Derived Air Concentration (DAC) values for these isotopes and the only nuclides that need be considered for air activation are ^{13}N and ^{15}O. Saturation activities for these nuclides are 14000 and 1500 $\mu Cim^{-1}\ kW^{-1}$ respectively where m is the path length for bremsstrahlung in air in meters and the kW applies to the electron beam power. Note that γ-rays are mainly responsible for the air activation since the cross sections for electrons are much lower. In our case, two factors help to minimize air activation; first, we place lead close to the accelerator section or beam pipe where accidental electron losses and hence γ production occurs and second, most of our electron losses will normally occur at energies below 7 MeV where activation is not a problem. If we assume, conservatively, that 10% of our electron beam losses occur at energies >7 MeV and that the air gap between the accelerator and the lead shielding is 5 cm, then the electron beam power is 8 watts and the saturation activities for ^{13}N and ^{15}O are 5.6 μCi and 0.6 μCi, respectively. For a room volume of 400 x 10^{6} ml this will give a total air activation of 1.55 x 10^{-8} μCi/ml, which is 0.4% of the DAC value of 4 x 10^{-6} μCi/ml. In practice the beam loss will be detected by the remote read out radiation monitors located at sites where beam loss is likely to occur and the linac operator will take action to correct the fault in this accidental loss mode so saturation activities will not be attained.

All of the accelerator sections and beam line components are water cooled by closed loop, low conductivity water systems, each of which utilizes a small makeup water tank. In no case will the electron beam strike the water pipe directly, so water activation can only occur due to bremsstrahlung radiation produced when electrons strike the copper discs of the accelerating structure or the stainless steel or aluminum beam pipe. Again, for normal operation, electron losses will occur at or near the injection energy so the γ-ray flux will be relatively low making activation of the machine components and the cooling water negligible. This is consistent with the observed results on the 120 MeV electron Linac for the NSLS, which operates at about the same average beam current as the ATF Linac and where the only activation that can be measured is in the momentum defining slits in the transport line where more than 50% of the electron beam is stopped. Levels of a few mR/hr can be measured at this location immediately after turning off the electron beam.

Activation of a copper beam stop utilized to stop the full electron beam are calculated from data in the report by W.P. Swanson. For 100 microbunches, 1nC/bunch at 6 pps, 120 MeV electron beam (average power 72 watts) we obtain saturation activities for Cu-61, Cu-62 and Cu-64 of 0.06, 1.08 and 0.36 Ci. This will give rise to a radiation field of 600 mR/hr at 1 m from the target

immediately on beam turn-off without shielding and assuming no self shielding in the target. After about 1 hr this would decay to about 15 mR/hr. A lead shield around the target will readily reduce the radiation levels to acceptable values.

Under normal operation the electron beam does not pass through air so there is no possibility for ozone production. For the accidental case described above we calculate that without any air change we would reach a saturation level of 0.005 ppm for 8 hrs. This is well below the TLV's listed by the ACGIH.

A NESHAPS permit has been issued for ATF operations but is not applicable (see Appendix VI). The application was made for the air activation values given above and was based on the maximum capability of the accelerator in terms of its maximum output and worst case condition for passage through air. It is therefore unlikely, if not impossible, to exceed the permitted limits. In the unlikely event that these limits are exceeded, the proper notifications will be made as specified in the approval letter from the EPA dated October 19, 1989.

Appendix V

Radiation Shielding

V.1 Gun, Linac and Transport Line Shielding

Here we are concerned with the problem of shielding to attenuate radiation produced by any of the loss modes described in Section 4.1.1 above. The shielding is designed to stop electrons and the resulting bremsstrahlung and x-rays in lead and then to absorb the neutrons thus produced in concrete or equivalent shielding. We estimate the shielding requirements for worst-case operation modes. Figure 4 shows the lead and concrete shielding for the linear accelerator and beam transport areas, and Figure 5 a cross-section of the Linac and shielding.

We assume that the Linac testing and alignment operation with "dark current" and photo electrons will be carried out for 100 hours per month in a combination of the modes described in section 4.1.1. However, monitoring of radiation levels and magnet currents should preclude operation at some of these loss levels for long periods of time. Faults, which create unusual radiation loss, will be detected by Chipmunk radiation monitors, which are located at sites where such losses may occur. These are read out and alarmed in the Control Room and machine operators are given written instructions and are trained to take actions appropriate to the level recorded by these monitors. High loss levels will result in the beam being turned off while the reason for that loss is determined. Thus accidental losses will not be sustained for more than a few minutes. For shielding calculations these accidental losses may be neglected when compared with normal operational losses detailed below.

For normal operation of 250 hours per month at the low energy end, losses of 1.3×10^{19} electron-MeV/ month occur at the collimator in the low energy transport line just upstream of the accelerating sections at an energy of up to 7 MeV. This assumes conservatively that 20% of the electrons are stopped at the collimator with the rest passing through it to be accelerated to higher energies. In addition, an estimated 10^{16} electron-MeV/month of electron losses occur in the electron gun itself, due to "dark current" electrons, at energies up to 7 MeV. This requires shielding of the electron gun region as well as the transport line slit region. Losses of up to 5×10^{19} electron-MeV/month also occur at the beam dumps in the experimental hall assuming 50% of the operating time, or 100 hours per month is at the maximum energy and charge.

The "dark current" electrons, which are emitted from all copper surfaces of the electron gun where fields in excess of 50 MV/m to 100MV/m are present, produce x-rays when they strike the walls of the gun cavity. Since these electrons have energy < 7 MeV they are stopped by the copper walls and produce x-rays locally. The electrons are accelerated in all directions by the electromagnetic fields in the radio frequency cavity of the electron gun and receive energy gains, which vary from 0 to 7 MeV. The 7 MeV electrons are only obtained by synchronous acceleration from the cathode surface at which they are emitted by field emission, across the 1.5 cells of the electron gun essentially along, or parallel to, the gun axis. Electrons are also produced at the exit aperture by field emissions there and they are accelerated towards the cathode, though not synchronously, thus gaining energies of up to about 3 MeV, again essentially along or parallel to the gun axis in this reverse direction. The copper cathode and a large Pb plug stop these reverse electrons.

The electrons which travel synchronously along or near the axis will exit from the gun in the normal way, will be focused by the beam transport solenoids and are measured on the collimator

faraday cup used to measure the normal electron beam. The measured peak "dark current" at 4.2 MeV/c in a test on the facility was 8 μA for 1 μsec. These forward electrons are only a small fraction

of the beam of electrons which are accelerated from the photocathode which suffer from the same, or similar, loss modes. Shielding for the normal electron current will, therefore, take care of any "dark current" electrons emitted in the forward direction. "Dark current" electrons traveling in all other directions will, however, require proper shielding.

We assume that up to 8 μA peak "dark current" electrons are accelerated towards the cathode to an average energy of 3 MeV for a period of 1 μsec, 6 times per second and calculate the x-rays produced and shielding required for this case. According to NCRP Report No. 51 the shielding transmission ratio for x-rays produced by these electrons is given by:

$$B_x = 1.67 \times 10^{-5} \left[\frac{H_M d^2}{D_{1o} T} \right]$$

where D_{lo} is the absorbed dose index rate (rads m^2 min^{-1}) at a standard reference distance of 1 m from the source. H_m is the maximum permissible dose-equivalent or dose limit rate ($mremh^{-1}$), d is the distance between the X-Ray source and the reference point (meters), T is the occupancy factor. If we assume conservatively 2000 hrs/year of gun operation and a 20% occupancy factor for the gun area we need to reduce the dose rate limit to 0.25 $mremh^{-1}$ in order to obtain the 100 mrem per year dose limit for radiation workers as well as meeting the BNL administrative dose limit of 25 mrem/year for non-radiation workers. Substituting these values in the above equation gives $B_x = 2 \times 10^{-3}$ for a lead shield starting 15 cm and ending 30 cm from the source. This would require 5" of lead in the forward direction. X-Ray radiation in the sideways (90E direction) is down by a factor of 4 compared to the (0E) case so 4" of lead is sufficient in that direction. In practice, only a small fraction of the "dark current" electrons reach the full 3 MeV energy at the cathode and the shield distance from the cathode is 30 cm rather than the 15 cm for the sideways (90E) direction so 4" of lead is an adequate shield in all directions.

The neutron yield per unit beam power, mainly arising from giant resonance neutrons, is nearly independent of electron energy at energies above 20 MeV and is taken from the calculations of W.P. Swanson (Health Physics 37 (1979) pages 347-358) as 2.1×10^{12} neutrons/k Joule for the full Linac operational loss mode. For 7 MeV operations we are below the threshold for neutron production so no neutrons are produced. For the experimental hall beam dump:

$$\phi = \frac{5 \times 10^{19} \frac{MeV}{month} \times \frac{12\, month}{year} \times 2.1 \times 10^{12} \frac{neutrons}{kJoule} \times 1.6 \times 10^{-16} \frac{kJoule}{MeV}}{4\pi (200cm)^2}$$

$$= 4 \times 10^{11}\, neutron/cm^2\, year$$

We will assume that ordinary concrete is used to shield the neutrons thus produced and use the formulation of NCRP Report #51 to calculate the shielding thickness required to reduce the dose

level at normally occupied areas of Building 820 and the Experimental Hall to 100 mRem per year. To reach this number a conversion factor of 2.5 x 10^{-13} rem cm^2 must be applied to the fluence at the Linac beam stops. This gives a value of 350 g/cm^2 or 148 cm of concrete for the beam stop regions.

The appropriate shielding is provided for these areas as described in Section V.2 of this document and the procedure for securing the Linear Accelerator Area is in Section 4.5.3.1.2.

V.2 Beam Transport Lines and Experimental Area

V.2.1 Introduction

An overview of the neutron, bremsstrahlung and x-ray shielding for the Accelerator Test Facility is given in Appendix V. This section expands on that information giving details of lead and concrete shielding configurations for the experimental hall and the Linac transport area of Building 820. Source terms and shielding calculations are also presented.

V.2.2 Operating Parameters

Using the current shielding, the linear accelerator has been approved to operate at 10% of maximum, i.e. 120 MeV and 60 nanocoulombs per second, time averaged over an increment of 1 hour (alternatively no more than 219 microcoluombs in one hour) by the Laboratory ES&H Committee (LESHC Minutes of Meeting 02-01, December 3, 2002). For the purposes of these calculations, however we consider energies up to 120 MeV with a maximum pulse repetition frequency of 6 Hz and a maximum charge of 1.0 nC in each of 100 microbunches contained in a 3.5 μsec macrobunch. Therefore, the maximum number of electrons accelerated to 120 MeV is 3.6 x 10^{12} per second. Under normal operating conditions, almost all of these electrons would reach the beam dumps situated in the experimental hall or at the end of the transport lines in the Building 820 high energy beam transport region (see Figures 1 and 2). Under certain conditions, some beam is lost at points along the beam line, such as near quadrupoles, or dipole bending magnets, or at collimators utilized to clean up the tails of the electron beam. We shall assume that up to 5% of the electron beam is lost at a single point in any of the above locations in any part of the beam transport system and calculate the shielding required to reduce the radiation levels to less than 100 mrem for the year. We shall further assume that the facility operates for 2400 hours per year with 1200 hours of operation at levels where the radiation levels are insignificant, i.e. less than 10^7 electrons per second accelerated to full energy.

V.2.3 Shielding Estimates

The primary lead shielding is for bremsstrahlung γ-rays produced by electrons striking the stainless steel of the beam transport pipe or the copper of the linac structure. Lead shields are placed at locations where such electron losses may occur. In essence, the primary γ-ray source is the lead shield itself since the energetic electrons easily pass through the beam pipe with little loss in energy. The 2" to 4" thick lead shield also gives rise to the production of photo neutrons which are then shielded by concrete enclosures around the lead. Any γ-rays which pass through the primary lead shield are readily stopped in this concrete shield wall so we will concentrate on the neutron shielding

calculations.

The calculations presented in the Section V.1 for the beam stops in the experimental area, and in

the linac tunnel in Building 820, estimated that, after the electrons were stopped there, for the above operating conditions, slightly less than 5 ft. of ordinary concrete is required to reduce the levels outside the shield to 100 mrem per year. If 5% of the beam can be lost at any point along the transport line this requires 3.5 ft. of ordinary concrete to reduce the radiation levels outside the shield

to 100 mrem/year. In the beam transport area of Building 820, there is a mezzanine above this line which contains accelerator equipment. The shield above this line must also be 3.5 ft. thick. In the experimental hall, the roof thickness must be sufficient to handle "skyshine" so we will use the methods presented in NCRP Report #51 to calculate the required shielding. (Here, we assume that the beam stops in this area are shielded by a full five feet of ordinary concrete or equivalent in all directions.)

V.2.4 Shielding for Skyshine of Neutrons

If we assume a steady 5% beam loss near a quadrupole or dipole bending magnet in either of the high current transport lines utilized for FEL or IFEL studies in the experimental area, and assume that this electron loss occurs in the lead shield, we can obtain the total neutron yield from Appendix F.3 of NCRP Report #51 as 2 x 10^{11} neutrons sec^{-1} μA^{-1}. The total number of electrons lost per second is 5% of 3.60 x 10^{12} or 1.8 x 10^{11} which is equivalent to an electron current of 1.8 x 10^{11} / 6x10^{12}, or approximately 3 x 10^{-2} μA. Then the neutron yield for all directions is Y = 2 x 10^{9} neutrons per second.

From Appendix F.4 we obtain the neutron fluence rate is $\varphi = Y_{sr\text{-}1}$ x 10^{-4} / d^2 where d is the distance from the source in meters. Also from F.4 we see that $Y_{sr\text{-}1,90}/Y_{sr\text{-}1,0} = 2$ so we obtain the neutron fluence φ_o at 90E as:

$$\phi_o = \frac{2x2x10^9 \, x \, 10^{-4}}{4\pi \, d^2} \, neutrons m^2 \, cm^{-2} \sec^{-1}$$

Since the experimental area roof is 1.4 m above the beam line, or source of neutrons, this gives φ_o = 1.6 x 10^4 neutrons m^2 cm^{-2} sec^{-1}.

Section 4.5.2 gives the roof shielding neutron transmission ratio, B_{ns}, for skyshine up to 20m from the source as:

$$B_{ns} = 3.3 \, x \, 10^{-3} \left[\frac{\dot{H}_M \, d_i^{\,2}}{\phi_o \Omega} \right]$$

Where $\dot{H}_m$ is the maximum allowable dose rate limit in $mremhr^{-1}$ and d_i is the distance between the source and 2 meters above the roof shield, Ω is the solid angle in steradians subtended by the neutron source and the shielding walls. We shall conservatively assume this angle to be 2π so that for $\dot{H}_m$ =100 mrem/1200 hrs we obtain:

$$B_{ns} = 3.3 \times 10^{-3} \left[\frac{\frac{100}{1200}(3.5)^2}{2 \times 10^4 \, 2\pi} \right] = 2.7 \times 10^{-8} \, rem \, cm^2$$

If we apply this to Appendix F.8 we obtain a concrete slab thickness of 50 gcm^{-2} or 22 cm of concrete. These shielding thicknesses for neutrons are more than adequate shielding for γ-rays which are primarily shielded by the lead near the beam line. For structural purposes the roof concrete thickness provided for the Experimental Area is 1.25 ft. or greater.

V.2.5 Entry Mazes

In order to enter the experimental area it is necessary to pass through a maze. Both the laser equipment area and the entrance foyer adjacent to the entrance from the Control Room area are considered to be controlled areas, while the experimental area is a high radiation area when beam is present. The nearest source of neutrons in the experimental area to either exit aperture is about 3 meters so the neutron fluence rate at the maze inner aperture is less than 10^3 neutrons cm^{-2} sec^{-1}. Both mazes are double legged and have a width of 3 ft. and a height of 7.5 ft. Section 4.4.2 gives the neutron transmission ratio through ducts, B_{nm}, as:

$$B_{nm} \leq \frac{270 \dot{H}_m}{K \phi_m} \quad where \; \dot{H}_m \; is \leq 5 \; mrem/hr.$$

and where K = 8 for a two-legged maze. Thus for our case, we obtain:

$$B_{nm} \leq \frac{270 \, x \, 5}{8 \, x \, 10^3} \quad i.e. \, B_{nm} \leq 0.17$$

From Appendix F.11 we obtain a center line distance of $2\sqrt{3x7.5}$ or 9 ft. in order to provide acceptable levels at the entry doors to the experimental area.

V.2.6 Shielding Design and Equipment Access

V.2.6.1 High Energy Beam Transport in Building 820

The shielding layout for the linac and low energy beam transport systems is given in Section V.1. The shielding for the high energy beam transport system is shown in Figures 2, 4 and 5. In order to align the transport elements with the shielding in place, it is necessary to provide a narrow accessway alongside the beam lines which is entered by removing a plug door. This plug door is on rollers with a winch and cable arrangement for opening it. The door is electrically interlocked so that

the rf system modulator cannot be turned on while the door is removed unless two independent interlock circuits which interrupt the modulator power supply are satisfied. It can be seen from Figures 5 and 6 that local lead shielding is provided near quadrupole and dipole magnets and around

collimating slits. At least 3.5 ft. of light concrete or heavy concrete equivalent is provided as required by Section 3 of this document and 5 ft. equivalent thickness is provided for the two beam stops as calculated Section V.1.

Because the accessway is potentially a high radiation area, a search and secure procedure and emergency stop buttons are provided for this area. Regular and emergency lighting and a telephone have been provided for the accessway.

V.2.6.2 Experimental Hall Shielding

The shielding for this area is shown in Figure 1b. Local lead γ-ray shielding is provided near quadrupole and dipole bending magnets and beam line collimators as necessary. A minimum of 3.5 ft. of concrete or equivalent is provided in the forward, backward and sideways directions for all loss points. A roof thickness of 1.25 ft. or greater of concrete is provided over the whole experimental area and entry mazes of greater than 9 ft. in length are provided at both entry points. All entry doors have dual safety interlocks. Sprinklers, emergency and regular lighting and air conditioning are provided for this area. Beam stop shielding is provided as detailed in Section V.1. The beam stops are entirely in vacuum so no air activation from primary electrons is possible.

Department of Energy
Brookhaven Area Office
Building 464
P.O. Box 5000
Upton, New York 11973

January 24, 1995

Dr. M. S. Davis
Associated Universities, Inc.
Brookhaven National Laboratory
Upton, New York 11973

Dear Dr. Davis:

SUBJECT: OPERATION OF THE ACCELERATOR TEST FACILITY (ATF) UP TO 120 MEV

The Brookhaven Area Office (BHO), Operations and Safety Management Division (OSMD), has reviewed the BNL Operational Readiness Review (ORR) of the ATF, the ATF's action plan and response, and the ORR's final concurrence.

BHO has subsequently conducted a walkthrough of the ATF that covered the equipment, accelerator, experimental, and control areas and included discussions with ATF staff on procedures, training, and system readiness for operation up to 120 MeV.

BHO found the facility to be in good order and in a state of readiness. BHO recognizes the good work done by the ATF and S&EP staffs to improve ATF practices and documentation with regard to safety and operations. Accordingly, BHO concurs with BNL's authorization to operate the ATF up to an energy of 120 MeV.

BHO fully expects that the ATF and S&EP staffs will continue to maintain the progress that has been demonstrated with respect to safety at the ATF. If you have any questions on this matter, please contact Pepin Carolan of my staff at extension 5966.

Sincerely,

Carson L. Nealy
Area Manager

cc: W. R. Casey, BNL
I. Ben-Zvi, BNL

Appendix VII

Shielding Policy

No changes to the radiation shielding shall be done that could compromise the safety of workers or the public or affect the ASE.

Staff and users are trained (ATF Facility Specific Training, i.e. ATF Awareness Training) to respect and maintain the ATF's primary shielding configuration. Primary shielding consists of the lead, concrete and other materials that enclose the ATF's accelerator, beam lines and experimental areas, as defined in this SAD. If there is any need to alter or remove primary shielding, a shielding permit (next page) must be in place before the work may begin. This authorization describes the job, the system affected, and the safeguards put into place to protect the workers during reconfiguration. The original permit is posted at the work site, and a copy is posted in the control room to notify the accelerator operator. Prior to the restart of Linac operations, the close out conditions of the permit must be satisfied. This typically includes inspection by ESH personnel, but may also include fault studies and additional documentation. This permit is reviewed by the Radiological Control Division's Facility Representative. Minor changes to shielding are done between ATF ESH officer and the lower-level RCD Supervisor using the permit. Minor changes that the RCD supervisor deems above his expertise are either resolved by review from a higher RCD supervisor or sent to the Physics Department's ESSH Committee. Major changes go straight to Physics ESSH Committee.

Appendix VII

Authorization for Work on ATF Accelerator Safety Systems
"ATF Shielding Permit"

This section to be completed by Requesting Personnel

Date: _____ **Person(s) Requesting Work Authorization:** _____

System(s) Affected: ☐ **Gun** ☐ **H-line/tunnel** ☐ **Beamline #** _____ ☐ **Other** _____

Date(s) work will be in progress: _____

Person(s) Doing Work: _____

Description of Work: ☐ **Temporary Removal of Shielding to Facilitate Access/Installation/Repair**

_____

_____

This section to be completed by Safety Personnel

Required Safeguard: ☐ **LOTO modulators** ☐ **LOTO Dipole** _____ ☐ **Other** _____

_____

Required Conditions or Restrictions on Work: _____

_____

☐ **Shielding to be Replaced to Identical Configuration**
☐ **ESH Officer to Visually Inspect & Document Upon Completion**
☐ **Related Attachments or Work Permit #** _____

☐ **Check Here if Changes Are Required in Shielding/Beamline Configuration** _____

☐ **Check Here if Review/Action Required by Physics ESSH Cmte. or Interlock Group**

Reviewed By (RCD/PESSHC): _____ **Date:** _____
(Name/Signature/Life#)

Safeguard Placed By: _____ **Time/Date:** _____
(Name/Signature/Life#)

Authorization Released By (ATF ESH): _____ **Date:** _____
(Name/Signature/Life#)

Return to Service or Close Out By: _____ **Date:** _____
(Name/Signature/Life#)

☐ **Check Here if Radiation Survey Required (List Beam Conditions & Requirements):**

_____

Survey By: _____ **Date:** _____
(Name/Signature/Life#)

- Original Copy of Approved Authorization Must be Posted at Work Site- Second Copy Must be Delivered to the Operator and Posted the Control Room

Radionuclide Production in Soil From 60 MeV Electrons at ATF

Introduction

A reorientation of the ATF beam line 1 resulted in a 90° bend toward the floor and the creation of a new stop to terminate the beam in. Because this orientation results in the forward directed beam pointed to the soil beneath the building, it was judged to be worthwhile to evaluate the potential for tritium and Na-22 production in soil. In a previous note from Hu to Gmur dated 1/10/02, the tritium production rate from neutron capture in naturally occurring deuterium was evaluated. In this note, we will also evaluate tritium and sodium-22 production from high energy neutron spallation.

Background

Activation in soil from the operation of accelerators has become an important issue at BNL. Considerable effort has been made at RHIC, BLIP, and the AGS to provide controls to minimize the production and dispersal of tritium in the soil, and questions are often raised about the steps that accelerators in the NSLS Complex have taken to prevent tritium production from its operations. (Note: tritium analyses were conducted of cooling water samples in 1997 and 2001; all values were below MDL.) It should be noted that there are several reasons why the potential for production of radionuclides in soil at the NSLS is very much lower than at our sister facilities such as AGS and RHIC. These factors can be used to qualitatively estimate the differences in radionuclide production in soil between these facilities.

One important reason is that the NSLS accelerates electrons rather than protons. The ability of electrons compared to protons to create non-elastic reactions in target materials is inherently smaller by a factor of about 100. Non-elastic reactions are required if spallation products such as tritium are to be produced in significant quantities. Secondly, the NSLS operates a much lower power levels than the proton facilities at BNL. For example, the x-ray ring at NSLS operates with a circulating beam of ~ 1×10^{12} electrons at 2.8 GeV produced once every 12 hours. The AGS operates with a 30 GeV beam of greater than 1×10^{13} protons produced every few seconds. Therefore, the AGS has ~10^6 greater beam power than the X-ray ring averaged over a 12 hour operating period. Combing the two factors, overall, the x-ray ring has ~ 10^{-8} less capability to produce residual radiation during a normal 12 hour operating period than the AGS does. Other NSLS accelerators such as SDL and ATF operate with higher beam power (but lower energies) than the storage ring, but still operate at several orders of magnitude less power than the AGS.

It is also possible to quantitatively estimate the level of induced tritium produced in the soil from electron beam interactions in a target. High energy electrons interacting in matter lose their energy primarily through production of bremsstrahlung radiation directed in the forward direction. The bremsstrahlung photons lose energy primarily

through interaction with atomic electrons, but some fraction of the photons will produce non-elastic collisions in a nucleus, thereby releasing high energy neutrons which can cause non-elastic interactions in other nuclei.

These high energy neutrons can produce radionuclides through spallation of the target nucleus. These production rates can be estimated through the following methodology.

In the ATF stop, the electron beam strikes a faraday cup and generates a bremsstrahlung beam that is intercepted by a 2" thick lead stop. In addition, there is a 12" concrete floor above the soil. Most of the neutrons will be created in the lead which represents a thick target of about 9 radiation lengths. The attached figure 1 provides an estimate of the high energy neutron (E > 25 MeV) production rates at 90°. Rohrig in attachment #2 (Ref. 1) has estimated that the dose at 0° is about four times as great as the rate at 90°. Using the value from attachment 1 at 100 MeV

$$H_{HEN} = 4 \times 0.1 = 0.4 \text{ Sv/hr-KW at 1 m}$$

The total power of the electron beam is 60 MeV x 1.5 nA = 9×10^{-2} watts. The neutron fluence to dose equivalent for HEN = 4 n/cm^2-s per mRem/hr. Therefore, the HEN fluence Φ at 1 m from the lead is:

$$\Phi = 0.4 \text{ Sv/hr-KW} \times 1 \times 10^5 \text{ mRem/Sv} \times 9 \times 10^{-5} \text{ KW} \times 4 \text{ n/cm}^2\text{-s/mRem/hr} = 14.4 \text{ n/cm}^2\text{-s}$$

Neutrons created in the lead must penetrate through 12" of concrete before entering the soil. The attenuation length in concrete for neutrons in this energy range is 55 g/cm^2.

$$\Phi = 14.4 \times e^{-12'' \times 2.54 \times 2.35 / 55} = 3.9 \text{ n/cm}^2\text{-s at 1 m}$$

We assume the soil starts at approximately 1/2 m from the target. Correcting for geometry, the fluence at the beginning of the soil is:

$$\Phi = 4 \times 3.9 \text{ n/cm}^2\text{-s} = 15.7 \text{ n/cm}^2\text{-s}$$

The tritium production rate A can be calculated from:

$$A = N\sigma\Phi(1 - e^{-\lambda t})$$

The cross section σ for tritium production from spallation in oxygen and silicon is taken as 10 millibarns (mb) from attachment 3 from reference 2. The number of target atoms per gram in soil (SiO_2) with density 1.6 g/cc is N:

$$N = 6.02 \times 10^{23} \text{ molecules per gram-mole} \times 3 \text{ atoms/molecule} \div 60 \text{ g/ g-mole}$$

$$N = 3 \times 10^{22} \text{ atoms / g}$$

t is the irradiation time and the tritium decay constant $\lambda = 0.056 \text{ yr}^{-1}$.

Therefore the tritium production "A" rate in disintegrations per second per gram of soil from one year of full time operation is

$$A(1\ yr) = 3 \times 10^{22} \times 10 \times 10^{-27} \times 15.7 \times (1 - e^{-0.056 \times 1}) =$$

$$A(1\ yr) = 2.56 \times 10^{-4}\ d/s/g$$

The actual operating time for ATF in this mode is approximately 750 hours per year which reduces the production rate in the course of the year to

$$A(1\ yr) = 2.56 \times 10^{-4}\ d/s/g \times 8.56 \times 10^{-2} = 2.2 \times 10^{-5}\ d/s/g = 6 \times 10^{-4}\ pCi/g\ H^3\ \text{in soil}$$

The Accelerator Safety Subject Area provides a methodology for determining the acceptability of induced activity in soil. In the model, all the radioactivity produced in one year is assumed to be located within 1 attenuation length of entry into the soil. This amount of tritium is concentrated within the water in the soil and is then diluted by the average height of rainfall in a year. The computed concentration in the assumed leachate is compared to 5% of the drinking water standard. It should be noted that this is a hypothetical calculation to determine whether engineered rain caps are needed. The ATF beam stop is within a building and the activated soil is covered by the footprint of the building. The beamstop is located ~6 meters from an exterior building wall.

Using this methodology, the concentration in soil is:

$$C\ (soil) = 6 \times 10^{-4}\ pCi/g \times 1.6\ g/cc = 9.6 \times 10^{-4}\ pCi/cc$$

Using the factors for calculating soil water leachate, we get:

$$C\ (H^3\ \text{soil water leachate}) = 9.6 \times 10^{-4}\ pCi/cc \div 0.1 \div 55 = 1.74 \times 10^{-4}\ pCi/cc = 0.17\ pCi/l$$

The Subject Area establishes that calculated H^3 leachate values in excess of 1000 pCi/l would require further safeguards and monitoring. Therefore, no corrective actions are required for this level of tritium production.

The subject area also requires that Na^{22} production be calculated. Cross-sections for Na^{22} production were not available, so the measurement and calculations for H^3 and production from SLAC RP-2000-07 (Ref. 3) were used to estimate Na^{22} productions rates. That report estimates that

$$A_{Sat.}(Na^{22}) = 1/2\ A_{Sat.}(H^3)$$

Using the equations given above, $A_{Sat.}(H^3)$ can be calculated to be

$$A_{Sat.}(H^3) = 0.127\ pCi/g$$

Therefore ,

$$A_{Sat.}(Na^{22}) = 6.4 \times 10^{-2}\ pCi/g$$

We can then calculate the production in one year to be:

$$A_{1\ yr..}(Na^{22}) = 1.5 \times 10^{-2}\ pCi/g \text{ or}$$

$$A_{750\ hours}(Na^{22}) = 1.28 \times 10^{-3}\ pCi/g$$

Using the methodology described in the subject area for sodium, it can be calculated that the concentration in soil water leachate for Na^{22} is

$$C\ (Na^{22} \text{ soil water leachate}) = 2.8 \times 10^{-5}\ pCi/cc = 2.8 \times 10^{-2}\ pCi/l$$

which is considerably lower than the action level of 20 pCi/l.

Conclusion

Tritium and sodium-22 production in soil from operation of ATF beam line 1 in the new configuration does not require any additional engineering controls or monitoring.

References

1. Norman Rohrig - "Evaluation of Required Additional Shielding for Hypothetical Accidental Losses from the BNL National Light Source from an Upgraded X-ray Ring Injector - Feb. 3, 2002
2. W.R. Nelson, A. Fasso, R. Sit, and S.N. Witebsky - "Estimate of Tritium Production in Groundwater near SLC Beam Dumps" Feb. 1998; SLAC RP Note 98/2R
3. James Liu and Sayed Rokni - "Analytical Method in Estimating the Induced radioactivity in Soil around High energy Accelerators" Oct, 2000; SLAC RP Note 2000-07

Attachment 1

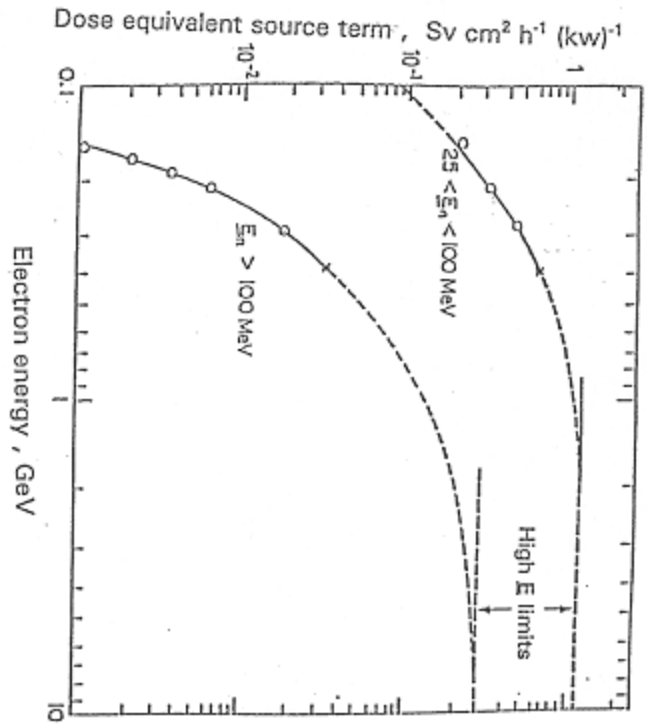

Fig. 4.21. Effective source terms for a thick copper target for neutrons of energy 25 to 100 MeV and for neutrons of energy greater than 100 MeV as a function of electron energy.

Attachment 2

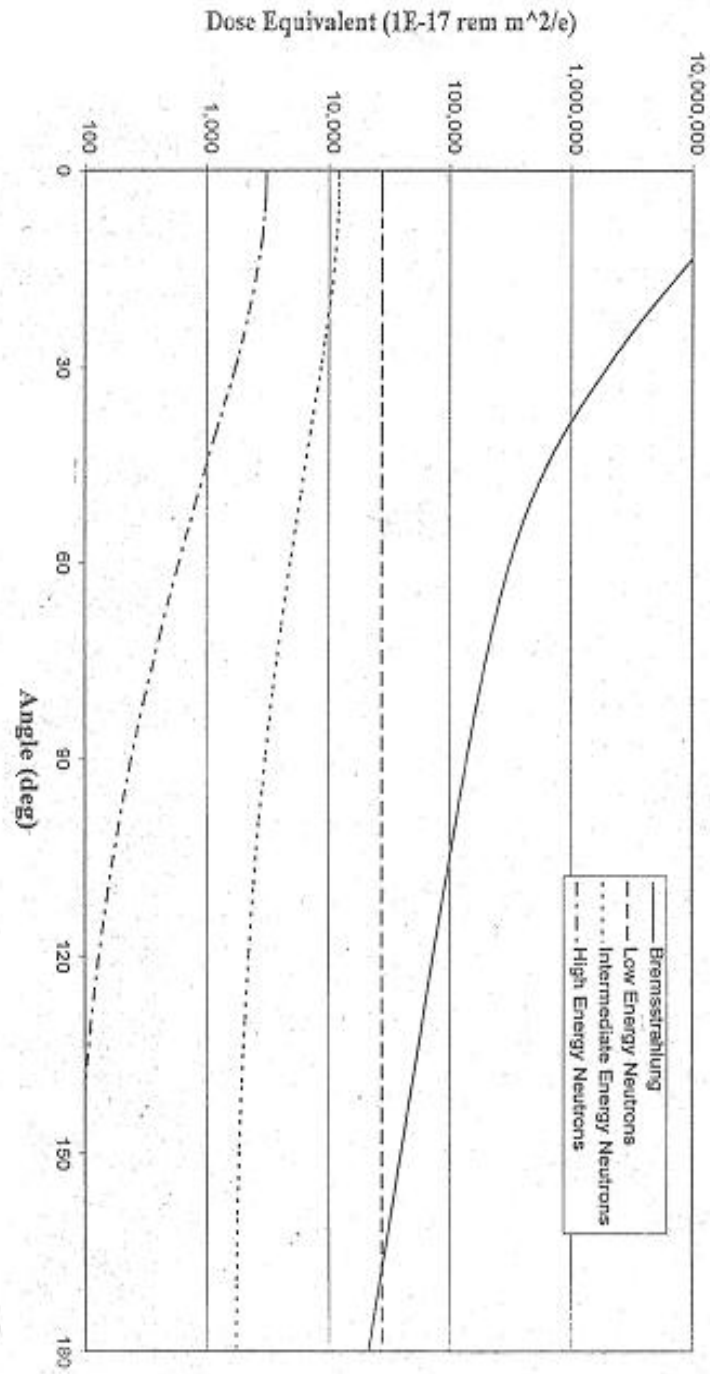

Figure 2: Unshielded Radiation Source Terms

Attachment 3

lateral to the dump calculates to be

$$A_\infty = (2.7 \times 10^{-10}\ {}^3\mathrm{H\,atoms/ml/e}) \times (6.25 \times 10^{12}\ \mathrm{e/s}) \times (1\ \mathrm{d/}{}^3\mathrm{H\,atom}) \times \left(\frac{10^6\,\mu\mathrm{Ci}}{3.7 \times 10^{10}\ \mathrm{d/s}}\right) = 4.6 \times 10^{-2}\ (\pm 34\%)\ \mu\mathrm{Ci/ml}$$

for a 50 kW beam running continuously.

An Independent Check on FLUKA Using SHIELD11

SHIELD11[7] is a fast and easy to use code for performing shielding analysis around a high-energy electron accelerator. It makes use of simple analytic expressions for the production and attenuation of photons and neutrons by electron beams striking thick targets, such as dumps, stoppers, collimators, and other beam devices. The formulae in SHIELD11 are based on the extrapolation (*i.e.*, scaling) of experimental data using rather simple physics ideas and the code has been used at SLAC for many years with great success.

Using the dimensions of the dump and vault provided in Figure 2, the high-energy neutron dose-equivalent rate, at a distance of 42-inches from and 90° to the beam direction, is estimated by SHIELD11 to be 7.4 rem/h/kW. With the conversion factor of 1.0×10^{-7} rem/n cm^{-2} recommended by Jenkins[12] the fluence rate calculates to be 1.0×10^6 n/cm^{2}s opposite the dump (point P_1 in Figure 2) for 50 kW of beam running continuously.

Now, cross sections for the formation of tritium by high-energy hadrons have been measured for various materials (*e.g.*, see Noguchi *et al.*[13]) and the results are summarized in Figure 5.

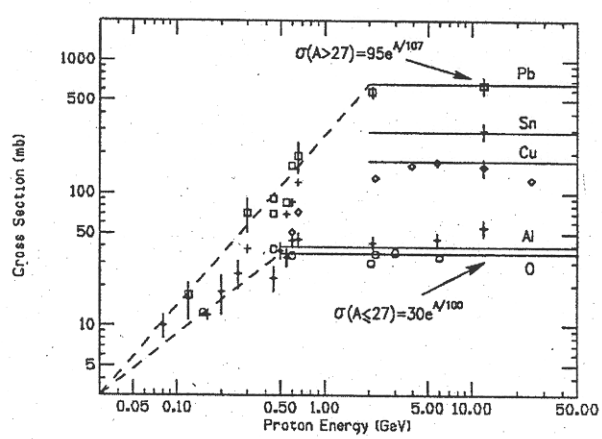

Fig. 5 Tritium formation cross sections as a function of proton energy.