LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

PHASE II SAFETY ANALYSIS REPORT NATIONAL SYNCHROTRON LIGHT SOURCE

Edited by P. Stefan

June 1989

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

NATIONAL SYNCHROTRON LIGHT SOURCE

**BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, LONG ISLAND, NEW YORK 11973
UNDER CONTRACT NO. DE-AC02-76CH00016 WITH THE
UNITED STATES DEPARTMENT OF ENERGY**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

**Phase II Safety Analysis Report
National Synchrotron Light Source**

June 30, 1989

CONTENTS

1. INTRODUCTION AND DESCRIPTION OF THE FACILITY (K. Batchelor)
 - 1.1 Introduction
 - 1.2 New Office Space and Experimental Areas
 - 1.3 New Radiation Sources
 - 1.3.1 General Introduction to Insertion Device Operation
 - 1.3.2 Soft X-ray Undulators
 - 1.3.3 Superconducting Wigglers
 - 1.3.4 Hybrid Wigglers
 - 1.3.5 Laser Electron Gamma Source (LEGS)
2. POLICY (K. Batchelor)
 - 2.1 Introduction
 - 2.2 NSLS Safety Committee
 - 2.3 Laboratory Safety Committee
 - 2.4 Safety Training
 - 2.5 Oversight of Operating Safety
 - 2.5.1 Follow-up on Safety Design
 - 2.5.2 Monitoring Safety of Experiments
 - 2.5.3 Beamline Commissioning and Unusual Operations
 - 2.5.4 Operating Radiation Standards
3. BUILDING SYSTEMS (A. Seifert)
 - 3.1 Introduction
 - 3.2 Building Access and Egress
 - 3.3 Hazards and Controls
 - 3.3.1 Controlled Entry to Experimental Areas
 - 3.3.2 Fire Hazard and Control
 - 3.3.2.1 Fire Protection
 - 3.3.2.2 Fire Detection
 - 3.3.2.3 Fire Alarms
 - 3.3.2.4 Fire-rated Construction
 - 3.3.2.5 Special Features

3.3.3 Occupational Health Hazards

- 3.3.3.1 Toxic Hazards
- 3.3.3.2 Laser Hazards
- 3.3.3.3 Radiation Hazards
- 3.3.3.4 High Pressure Systems
- 3.3.3.5 Chemical Storage
- 3.3.3.6 Ozone Production (N. Gmur)
- 3.3.3.7 Cryogenic Hazards (M. Iarocci)
- 3.3.3.8 Environmental Hazards
- 3.3.3.9 Magnetic Field Hazards

3.3.4 Emergency Power and Lighting

3.4 Laser Electron Gamma Source Facility

3.6 Infra-red Platform

3.5 R.F. Extension

4. EXPERIMENTAL AREAS--INSERTION DEVICE BEAMLINES

4.1 Soft X-ray Undulators (H. Rarback)

- 4.1.1 Introduction
- 4.1.2 Device and Beamline Operation
- 4.1.3 Hazards and Controls

- 4.1.3.1 Device Hazard
- 4.1.3.2 Electrical Hazards
- 4.1.3.3 Cryogenic Hazard
- 4.1.3.4 Occupational Health Hazards
- 4.1.3.5 Visible Light Hazard
- 4.1.3.6 Radiation Hazards
- 4.1.3.7 Beam Heating Hazards

4.2 High-Energy High-Power Superconducting Wiggler Beamlines

- 4.2.1 Introduction (W. Thomlinson)
- 4.2.2 Accident Assessment (W. Thomlinson)
- 4.2.3 Radiation Hazards (D. Chapman and N. Gmur)
 - 4.2.3.1 Shielding Requirements
 - 4.2.3.2 Operation of Tandem Hutches

4.3 Hybrid Wiggler Beamlines - X21/25 (L. Berman)

- 4.3.1 Introduction
- 4.3.2 Front End
- 4.3.3 Transport Section
- 4.3.4 Hutch

5. LASER ELECTRON GAMMA SOURCE-LEGS (A. Sandorfi)

- 5.1 Introduction and description of LEGS
- 5.2 Description of LEGS Operation

5.3 Hazards and their controls

5.3.1 Radiation hazards and shielding

5.3.1.1 Synchrotron radiation

5.3.1.2 Gamma radiation

5.3.1.2.1 Hazard level of the LEGS beam

5.3.1.2.2 LEGS gamma-ray and bremsstrahlung shielding

5.3.1.2.3 Sweeping magnet for secondary charged particles

5.3.1.2.4 Radiation level outside interlocked areas

5.3.1.2.5 Target room shielding

5.3.1.2.6 Radiation interlocks

5.3.1.3 Tagging electron cave

5.3.1.3.1 Shielding

5.3.1.3.2 Interlocks

5.3.2 Electrical hazards

5.3.3 Laser light hazards

5.3.3.1 UV laser

5.3.3.2 CO₂ laser

5.3.4 Cryogenic hazards

5.3.5 Egress

5.3.6 Accident assessment

5.4 Attachments

5.4.1 List of Tables

5.4.2 List of Figures

6. REFERENCES

7. APPENDIX

7.1 NSLS Memorandum, February 28, 1989, Source Size for Maximum Credible Accident in the Storage Rings (K. Batchelor)

7.2 BNL Memorandum, April 14, 1989, Magnet Alloys - Bldg. 725 (J. Levesque)

7.3 A Thermal Absorber for High Power Density Photon Beams (S. Ulc and S. Sharma)

7.4 The Superconducting Wiggler Beamport at the National Synchrotron Light Source (W. Thomlinson, D. Chapman, N. Gmur, and N. Lazarz)

7.5 Radiation Safety Systems at the NSLS (T. Dickinson)

7.6 BNL Memorandum, June 29, 1988, Cryogenic Safety Committee Minutes of Meeting held June 29, 1988, (NSLS User Liquid Nitrogen Storage System)

7.7 BNL Memorandum, December 22, 1986, Cryogenic Safety Committee Minutes of Meeting held December 11, 1986, (NSLS Superconducting Wiggler Magnet Cryogenic System)

PHASE II SAFETY ANALYSIS REPORT

1. INTRODUCTION AND DESCRIPTION OF THE FACILITY

1.1 Introduction

The Phase II program was established in order to provide additional space for experiments, and also staging and equipment storage areas. It also provides additional office space and new types of advanced instrumentation for users. This document will deal with the new safety issues resulting from this extensive expansion program, and should be used as a supplement to BNL Report #51584 "National Synchrotron Light Source Safety Analysis Report", July 1982 (hereafter referred to as the Phase I SAR).

The initial NSLS facility is described in the Phase I SAR. It comprises two electron storage rings, an injection system common to both, experimental beam lines and equipment, and office and support areas, all of which are housed in a 74000 sq. ft. building. The X-ray Ring provides for 28 primary beam ports and the VUV Ring, 16. Each port is capable of division into 2 or 3 separate beam lines. All ports receive their synchrotron light from conventional bending magnet sources, the magnets being part of the storage ring lattice. Fig. 3.1 illustrates the general arrangement of the ground floor of the present NSLS Facility.

1.2 New Office Space and Experimental Areas

The response from users placed a demand on the NSLS facility far surpassing those resources provided by the Phase I program. In order to support further development of the facility, it was necessary to provide additional floor, laboratory, and staging space.

Section 3 of this report will deal with the safety issues related to these expanded spaces such as access and egress, fire protection, drainage systems, chemical storage, and emergency power. Section 3.3.3.3 deals with the radiation hazards for non-radiation workers who may occupy offices adjacent to the Booster and VUV Storage Rings.

1.3 New Radiation Sources

1.3.1 General Introduction to Insertion Device Operation

There was a desire to improve the spectral capabilities of the storage rings and to provide for this, several types of instruments were designed for installation as insertion devices in the storage rings.

The high flux available from these insertion devices necessitated a redesign of the vacuum chamber and its associated cooling system. New power supplies for the X-ray storage ring magnets allow for operation at energies up to 2.8 GeV. However, special studies are required to set the correct magnet control parameters to attain these energies. To prevent any possibility of accidental operation at energies significantly greater than 2.5 GeV there is a current relay which will trip out the dipole magnet power supply if the 2.5 GeV value is exceeded by a few per cent. Also there is insufficient r.f. power available at current operating levels to sustain higher energy operation. As an additional safety precaution, software limits are placed on all magnet power supplies for the ring.

This document will address X-ray Ring operation at energies up to 2.5 GeV.

1.3.2 Soft X-ray Undulators

These are designed to increase the photon flux at a specific x-ray energy and thus produce similar shielding requirements to the existing bending magnet sources. The main difference as far as shielding is concerned is the fact that the potential bremsstrahlung source size is larger. A memorandum detailing the source size for the design of beamline shielding was issued to beamline designers and existing users on February 28, 1989 and is included as Appendix 7.1 of this report. A detailed discussion of safety issues related to soft x-ray undulators is presented in Section 4.1.

1.3.3 Superconducting Wigglers

These devices provide an x-ray source for materials science studies, and for angiography studies on human subjects. They extend the useful spectral energy range to ≈ 150 keV (or push the usable photon wavelength limit down to $<0.1\text{\AA}$). With this harder x-ray spectrum, it is necessary to increase the wall thickness of beam pipes or hutches in order to provide the necessary shielding. A detailed discussion of the safety issues related to these devices is given in Section 4.2.

1.3.4 Hybrid Wigglers

These are devices which utilize a series of permanent magnets to produce a photon spectrum similar to that of a regular X-ray Ring bending magnet but with a photon flux about 30 times as intense. Special beamline shielding problems exist only where the photon beam encounters matter in some form. At such points, extra lead shielding is required. A detailed discussion of safety issues related to Hybrid Wiggler operation is contained in Section 4.3.

1.3.5 Laser Electron Gamma Source (LEGS)

This is a source of high energy γ -rays (≈ 300 MeV to 500 MeV) produced by back-scattering the photons provided by a laser source off the electrons in a straight section of the X-ray Ring. These back-scattered photons are inherently well-confined and many of the beamline shielding requirements relate to the shielding for this γ -ray beam. The requirements for bremsstrahlung shielding are similar to those for any of the insertion devices described above. A detailed study of safety issues related to LEGS is contained in Section 5.

2. POLICY

2.1 Introduction

NSLS has a strong commitment to safety as witnessed by the fact that, in addition to the usual Safety Coordinator (K. Batchelor), there are also a Safety Officer (T. Dickinson), and Assistant Safety Officer (C. Auguste) whose duties are to ensure the safe operation of the facility and to arrange for safety training for both NSLS staff and users. In addition, C. Flood of S&EP Division works with the department on safety matters and two other members of the S&EP Division, C. Weilandics and R. Zantopp are assigned to the NSLS on a full time basis.

2.2 NSLS Safety Committee

The NSLS Safety Committee reviews all phases of the NSLS program and makes recommendations regarding safety matters. This committee is made up of the following people.

K. Batchelor	- NSLS Department Safety Coordinator
C. Flood	- Safety and Environmental Protection Division
T. Dickinson	- NSLS Safety Officer
N. Fewell	- Operations Engineer, NSLS
R. Klaffky	- Chair, Beam Line Review Committee
R. Larson	- Electrical Engineer for Safety Systems, NSLS
T. Oversluizen	- Mechanical Engineer, NSLS
N. Rohrig	- Physicist, S&EP Division
C. Weilandics	- Health Physicist, S&EP Division
G. Williams	- Physicist, NSLS Experimental Group

This committee reviews each experimental station before it becomes part of the operating facility and any major modification requires a further review. It also reviews all new construction items in the total NSLS facility.

2.3 Laboratory Safety Committee

Whenever changes not covered by this document or by the Phase I SAR (BNL 51584) or requiring a new SAR are made by the Department Safety Committee, they are brought to the Laboratory Safety Committee for their review. The policies are not implemented until such a review has taken place and approval has been obtained from the Director's Office. In addition, members of the Safety and Environmental Protection Division act as advisors to the Department on safety matters.

2.4 Safety Training

In addition to the training discussed in detail in Section 2.4 of the Phase I SAR (BNL 51584), namely that for NSLS Operators, a training program for NSLS Users is now in place. All users are required to watch an eleven-minute safety video tape, which provides an introduction to experimental hutch entry systems, as well as a description of radiation safety, fire alarms, and evacuation procedures particular to the NSLS. Users who will be staying for more than two weeks, or who will be returning repeatedly, are required to attend the New Employee Safety Orientation and the Film Badge Wearer's Orientation given by the S&EP Division.

2.5 Oversight of Operating Safety

2.5.1 Follow-up On Safety Design

At the formal review of a beamline, the shielding design and other safety features are defined, and these are recorded in the drawings and other documents which emerge from that review. When the beamline has been constructed, a check list is compiled (by beamline personnel, in consultation with the NSLS Safety Officer) which documents the individual shields, flange locks, exclusion zones and other items necessary for safe operation. A new copy of this check list is executed and signed by beamline personnel, and initialled by the Operations Coordinator, each time the beamline is turned on from a "locked out" state, such as when a new experiment comes on line, or after the line has been shut down. This occurs at least once a month for each beamline, due to the storage ring maintenance and studies schedule.

A beamline radiation safety system interfaces each beamline to the overall radiation safety system. These systems are described in Appendix 7.5. Once the beamline and its safety system are constructed, a certification test procedure for the system is designed by the NSLS Safety Officer. Every 6 months, each beamline is re-certified by the Safety Officer and the Operations Coordinator staff using its test procedure.

2.5.2 Monitoring Safety of Experiments

An Experimental Safety Approval Form (see Fig. 2.1 and 2.2) must be submitted for each experiment, listing the materials, equipment, and personnel involved. The experiment is reviewed for hazards and the form is approved by the NSLS Safety Officer. The approved form must be posted at the beamline whenever the experiment is running, and serves as a valuable aid to the operations staff in keeping track of activities and personnel on the experimental floor. Approved experiments may run for up to six months before a new form and review is required.

Formalities such as approval forms and check lists are necessary because of the scale of operations. There can be as many as fifty experiments running at once at the NSLS, and the number continues to increase. An attempt has been made to integrate the formalities into the normal flow of activities and to avoid bogging down in red tape.

2.5.3 Beamline Commissioning and Unusual Operations

When a beamline is first constructed, it is often necessary to locate the position of the beam at one or more intermediate points along the line, usually while correlating these positions with displacements of the electron beam in the storage ring. These measurements are usually done with temporary shielding and with portions of the beamline not in place. Such operations are carefully reviewed by the Safety Officer, beamline staff, and operations staff. They are continuously monitored by a member of the operations staff who controls beam shutter operation and access to areas of potential radiation. Special operations to deal with equipment or radiation problems are handled in the same way. In all cases the standards on radiation area access and protection are met, as defined in section 3.4.0 of the BNL Safety Manual.

NSLS EXPERIMENTAL SAFETY APPROVAL

NOTE: No experiment will be allowed to run without a properly completed and approved experimental safety approval form. This form must be submitted at least one week prior to commencement of experiment or experiment will not run.

Date Submitted: _____ Safety Officer
Approval: _____ Date

1. Experiment ID# (General Users leave blank) 2. Expected Start Date: _____

beam line year sequence number 3. Expected Duration: _____
(must be reviewed every six months)

4. Program Personnel

First and Last Name	Affiliation	Phone Number
---------------------	-------------	--------------

_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

5. Experimental Title: _____

6. Materials to be used: _____

7. Equipment which is not a permanent part of the beam line: _____

8. User Comments: _____

9. Safety Officer's Comments: _____

**Fig. 2.1 NSLS Experimental Safety Approval Form
Front Side.**

INSTRUCTIONS FOR COMPLETION OF NSLS EXPERIMENTAL SAFETY APPROVAL FORM

All forms should be submitted to the NSLS Receptionist at the address below at least one week before experiment starts. General Users should submit Safety Approval Form with proposal directly to the User Administration Office. If an experiment involves hazards requiring special procedures or equipment, discussions with the Safety Officer should start significantly earlier.

NSLS Receptionist
NSLS Department, Building 725
Brookhaven National Laboratory
Upton, NY 11973
(516) 282-4746

Item-by-Item Instructions

1. The experiment ID will have the form beam line, year, sequence, e.g., U14A-86-19. This will be assigned by the person who schedules your beam line.
- 2&3. The duration of a safety approval cannot exceed six months. Continuing or recurring experiments must be reviewed each six months.
4. Most important are the names of those who will be running the experiment and will know the technical details. If there is a local contact who can help in answering questions, he/she should be named. Please give first names rather than initials unless there is a reason for withholding this information.
5. For example: "Photoemission of CO on Si(111)."
6. List all materials which will be studied, or used to prepare samples. If you have data on hazards, send it along to help in the review process. Indicate how you will dispose of hazardous materials.
7. List equipment you will add to the beam line or use in the experiment. Include any lasers, ovens, pumps, pressure cells, cryostats, cryopumps, sorption pumps, and any other equipment which might present a hazard.
8. Include any comments which might assist the NSLS staff in helping the experiment along or in responding to problems.

NOTE: When ready to run the experiment, contact the Operation Coordinator on beeper #824; the coordinator will post the approved form on the beam line.

Fig. 2.2 NSLS Experimental Safety Approval Form
Back Side.

Even after a beamline is fully assembled and aligned, several restrictions are placed on initial operation, such as reduced current, frequent radiation surveys, and no unattended operation. The idea is to focus attention on the beamline, and to catch problems that "no one has thought of yet". When it becomes clear that the experimental equipment and the support and safety systems are working smoothly, the line is released for normal operation. This usually occurs in one or two weeks. The period of restricted operation for the Phase II beamlines will last somewhat longer, since these operations will be breaking new ground.

2.5.4 Operating Radiation Standards

Radiation levels allowed during operation are determined by ALARA, (As Low As Reasonably Achievable), and the pertinent question is "what is reasonable?". At the NSLS, reasonably achievable levels are different for synchrotron radiation and bremsstrahlung, because of operating considerations and differences in shielding requirements.

In the case of synchrotron radiation from the beamlines, our standard is to make the beamlines "quiet" to a pancake Geiger counter, which results in levels less than 0.1 mR/hr. This level is not a significant exposure hazard, since practical exposure levels would be much less than the radiation levels measured in contact with the beam pipe. However, this standard makes it easy to detect new radiation leaks. Detected levels above this standard (up to a few thousand counts/minute [about 1mR/hr]), are noted and beamline personnel are requested to correct the leaks at the next maintenance period. When higher levels are encountered, advice is obtained from safety professionals, and if radiation above 5 mR/hr is measured on an ion chamber survey meter, the operation must be modified to reduce levels, or operation must be terminated until shielding is corrected. An exception to this rule is special operations, which are monitored by a safety professional. These standards are reasonable because the synchrotron radiation is easy to shield against.

The high energy bremsstrahlung and neutron radiation from the storage rings and injector is more difficult to shield, and the ALARA goal is to keep actual exposures below the standards for non-radiation workers, as outlined in Safety Manual section 3.1.0. Personnel monitoring of NSLS radiation workers has shown this to be successful. Data from the NSLS

environmental monitoring program has been used in the design of shielding improvements which maintain radiation levels within the revised guidelines for accessible and continuously occupied areas. Section 3.3.3.3 of this SAR provides more details on this program.

The limited areas where significant radiation has been found are posted according to section 3.4.0 of the Safety Manual, and administrative controls are used to minimize exposures.

3. BUILDING SYSTEMS

3.1 Introduction

The building systems such as heating, ventilating, air conditioning, compressed air, water and fire protection systems are designed to serve only the expanded areas of the building. The lower level of the two-story addition was constructed at the same floor elevation as the existing building and it is comprised of the expanded VUV and X-ray experimental floor areas, a small user lounge, bathrooms, mechanical equipment rooms, several offices, the angiography suite, three laboratories, and two dark rooms, as can be seen in Fig. 3.1. The second floor area, constructed at the same floor elevation as the existing building, is devoted to staff offices, a design room, mechanical equipment rooms, library, conference and seminar rooms, bathrooms, kitchen/copy rooms, and an ozalid printing room, as can be seen in Fig. 3.2.

3.2 Building Access and Egress

Since the Phase II project is an addition to the existing building, personnel have full access between the existing building and the addition at the VUV and X-ray experimental floor level, as can be seen in Fig. 3.1. There are also a number of new entrances to access the addition from the exterior at grade level. Adjacent to the existing truck lock off Technology Street, there is a double door that permits entry into an area designated as Storage. On the north side of the building opposite Building 535, there is an entrance lobby and elevator designed to permit the delivery of angiography patients to the lower first floor level and stair No. 2 that allows personnel to access the second floor or the first floor. On the northeast side of the addition, there are two locations accessible from

grade. The truck lock and its associated man door permits access directly into the expanded X-ray floor, and approximately 50 feet away a man door provides entry into stairway No. 1 which either leads to a locked door that permits access directly to the expanded VUV experimental floor or to the second floor office area. The new expanded lobby area is accessed via the existing main entrance situated off Brookhaven Avenue. However, personnel cannot access either the experimental areas of the first floor or the second floor offices from this location. An additional entrance into the experimental floor area is provided for by a tunnel connecting the basement of Building 535 and the expanded X-ray floor on the north side. Access to the second floor is through the two stairs mentioned previously and also by a balcony walkway connecting the existing building's second floor with the new addition in the vicinity of the expanded lobby area. At the west end of the second floor corridor an emergency stair leads directly to the exterior at grade level. The number and locations of egresses for the building addition satisfies the requirements of NFPA 101 and BNL OHS Guide 4.1.2.

3.3 Hazards and Controls

3.3.1 Controlled Entry to Experimental Areas

Since both the X-ray and VUV experimental areas are considered potential radiation areas, film badges are required for most personnel entering these areas. All entry points to these areas are controlled by utilization of a key pad attached to the door jams. Visitors as appropriate will be given temporary film badges or will be accompanied by an authorized user whenever they enter these areas. The detailed policy regarding visitors and film badges is covered in NSLS Bulletin 88-17, April 11, 1988.

3.3.2 Fire Hazard and Control

The Light source facility relies on several different methods of fire protection. These include portable fire extinguishers, combined sprinkler and fire standpipe system, smoke and heat detectors, fire area separation, manual fire alarm stations, and an annunciator and signal system that is tied into the Site Fire Alarm System.

Fig. 3.1

Fig. 3.2

3.3.2.1 Fire Protection

Approximately 14 portable Halon 1211 fire extinguishers (UL rated 3A:80BC) are located throughout the building. The maximum travel distance to a fire extinguisher is approximately 75 feet.

A sprinkler system is provided throughout the facility. There are two types of systems installed, one is a preaction type, which is utilized in all areas with electronic equipment and which requires sensing of smoke by a smoke detector to fill the normally-dry system with water, ready for action should a sprinkler head fuse and ultimately melt. The other system, which is in use in all other areas, is called the wet system. In this system, which is direct action, the sprinkler heads are attached to the piping system which contains water under pressure at all times. When the sprinkler heads sense a temperature sufficiently high (212°F for exposed heads and 165°F for concealed heads) so that the link fuses, water will discharge.

The standpipe system is enclosed in recessed wall cabinets located at the first and second floor landings of each stairway. The cabinets contain a portable fire extinguisher and a hose valve for connection of the Fire Department's fire hose.

The sprinkler system, as installed, consists of two preaction sprinkler zones and two wet sprinkler zones. The two preaction zones cover the following areas: one zone for the expanded VUV area and User Lounge on the first floor, and one zone for the X-ray experimental areas including the Data Control Room and Electronics Lab. One wet sprinkler zone covers the entire second floor office space, including the mechanical equipment and design rooms, ozalid room, seminar, conference rooms, library, and kitchen/copy rooms. The stairway fire hose cabinets (standpipe system) are also on the wet systems.

In addition to the automatic systems described above, there are manual fire alarm stations within the preaction zones. Activation of the manual fire alarm station in any zone will allow water to enter and fill the sprinkler piping of its respective zone. Activation of a manual emergency release (MER) valve, located at the sprinkler station, will also result in water filling in its respective piping zone. Consequently, operation of the fire detection system alone or manual fire alarm station alone or manual

emergency release alone or fusing of a sprinkler head alone will not result in the discharge of water into the preaction areas.

3.3.2.2 Fire Detection

In the preaction areas, there is a pattern of smoke detector alternating between ionization type and photoelectric types. The sensing of smoke by a detector will activate the preaction system and release water into the sprinkler piping. The water will remain in the piping until the fuse of the sprinkler head melts, as with a conventional wet system, thus opening the head and discharging water. In some locations, such as toilets, heat detectors are used in lieu of smoke detectors.

Five zones have been established for the distribution of conditioned air in the facility. These include one HVAC zone for the second floor and office and laboratory areas of the first floor, one HVAC zone for the VUV and X-ray experimental areas, one zone for the fume hoods makeup air system, one zone for the chemical storage area, and one zone for the second floor office addition. The supply and return air ducts for the three HVAC systems have ionization-type smoke detectors installed. When the units detect the presence of smoke, they will sound a fire alarm. They will also cause the fans to shut down and the smoke dampers to close off the respective zone, preventing air circulation. (Exhaust fans for fume hoods and other exhaust systems continue to operate, even when the HVAC fans shutdown.)

Additionally, the supply duct of the fume hood makeup air system has a smoke detector that will cause the supply fan to shutdown on detecting products of combustion and will send a signal to the fire alarm panel.

3.3.2.3 Fire Alarms

The activation of any detector or manual fire alarm station in the preaction systems will de-energize a solenoid valve which will allow water to fill the sprinkler piping and will also energize an audible alarm. The fusing of a sprinkler head in the wet pipe system, which permits water to discharge, will also sound the fire alarm system. Alarms are sounded locally and at the Fire Alarm Control Panel.

The preaction sprinkler system is supervised by pressurized air. Damage to a sprinkler head or sprinkler piping will result in the loss of supervisory pressure. This drop in pressure will send a signal to the BNL Fire and Rescue Group. A local trouble bell also sounds at the sprinkler station.

Continuously ringing fire alarm bells are used to alert building occupants once a fire alarm signal is initiated. Intermittent ringing of the fire alarm bells to notify building occupants to evacuate the building is initiated by a manually-operated alarm in the Control Room. To shorten the Fire Department's time in locating a fire in the building, the entire alarm detection system is subdivided into 35 zones. Thirty-two zones were used for the original building and three zones have been added to accommodate the addition. Upon activation of any detector or sprinkler waterflow, all alarm signaling units will sound continuously and the respective zone alarm lamps will light on the Fire Alarm Control Panel. For purposes of operation and maintenance, whenever any of the elements of the fire protection system are not operable or the system is not in its normal operating mode, a visual and audible signal will result at the Fire Alarm Control Panel. All the alarm and detection systems operate off the normal building power supply. However, the system has an automatic emergency battery supply that will operate for a period of 24 hours, if normal power is interrupted.

These fire alarm systems comply with DOE-mandated fire alarm codes NFPA 72A, NFPA 72D, and NFPA 72E.

3.3.2.4 Fire-rated Construction

Fire area separation is achieved between the second floor offices and the exit corridor by one-hour-rated partitions, and doors and frames which meet or exceed the 20 minute minimum fire-rating requirement of NFPA 101.

All building construction is classified as non-combustible. The steel roof deck assembly is UL Class A listed and FM Class I approved. All interior finishes have a flame spread less than 25 and smoke development under 50, as per ASTM E-84. Exterior insulated wall panels meet UL and FM criteria for flame spread and smoke development, and comply with DOE guidelines for UL and FM ratings on large-scale corner tests, without sprinkler protection.

3.3.2.5 Special Features

There are no smoke or thermal detectors in areas protected by the wet sprinkler system except for the elevator lobbies at each of the three landings, which have smoke detectors interlocked with the elevator automatic recall, and at the second floor entrance to the addition, where a double door has a magnetic release tied to smoke detectors to isolate the expanded lobby and existing building from the new addition in case of fire.

3.3.3 Occupational Health Hazards

The hazards associated with this facility are no different from those encountered in the original building and are discussed fully in the NSLS Safety Analysis Report dated July 1982.

3.3.3.1 Toxic Hazards

Users are required to submit a list of materials involved in their experiments to the NSLS Safety Officer for review and approval (see Fig. 2.1 and 2.2). Several laboratories with fume hoods and other facilities are available for sample preparation, and a steward has been assigned to each of these labs to coordinate such activities. The steward reviews the proposed activity, decides if further review of materials or processes is needed, and schedules the work to avoid conflicts in space or incompatible materials. Chemical storage and waste collection are described in section 3.3.3.5.

The ozalid print room on the second floor will contain a maximum of two Anhydrous Ammonia gas cylinders for use with the print machine. One cylinder will be full but not in use and the second cylinder will be valved and in use. Both cylinders are securely fastened to the wall. The exhaust from the ozalid machine is ducted directly to the atmosphere through a fan

and high vertical stack on the roof, assuring a negative pressure in the duct exhaust system. The exhaust system conforms to BNL OHS Guide 2.2.6.

3.3.3.2 Laser Hazards

Conventional laser systems will be in common use for alignment purposes in one or more of the NSLS laboratories. These systems are subject to the BNL controls described in the BNL Safety Manual section 2.3.1.

High-power laser systems are used in the LEGS program on X-5, and are described in section 5.3.3.

3.3.3.3 Radiation Hazards

NSLS policy with regard to radiation safety in essence follows the ALARA guide. Shielding is designed to keep radiation levels in continuously occupied areas below 0.5 mrem/hr and the yearly accumulated dose to non-radiation workers who occupy offices adjacent to the Booster and VUV Storage Rings below 100 mrem per year (DOE Order S800.11, "Radiation Protection of Occupational Workers").

Lead and concrete shielding has been designed and placed in areas around the rings where both normal and unusual beam losses are expected to occur. In order to determine the effectiveness of this shielding, a long-term program of radiation monitoring involving TLD's placed in appropriate areas around the facility, including certain offices above the Booster and overlooking the VUV Storage Ring, has been implemented. With the commissioning of the new insertion devices in the X-ray Ring, this monitoring program is being extended to include that area.

3.3.3.4 High Pressure Systems

Two 10 H.P. compressors provide 40 cfm each to an air receiver which distributes compressed air at 100 psi to the laboratories and hoods. At each hood, the pressure is reduced to 65 psi and at the laboratory benches the air pressure is reduced to 15 psi.

The 120 gallon compressed air receiver is equipped with a safety valve, pressure gauge, and service and drain valves. The vessel is ASME approved.

All piping conforms to ASTM-B88 and ANSI-H23.1.

All fittings and unions conform to ANSI-B16.22.

Pressure relief valves are ASME approved.

After installation, the entire piping system was tested to 175 psig.

3.3.3.5 Chemical Storage

Flammable materials storage cabinets have been provided at four locations on the experimental floors, and in the vacuum and machine shops. The goal in providing this convenient, proper storage is to minimize the amounts of solvents stored at the beamlines and in work areas. In addition, flammable storage and corrosives cabinets are being installed in the user laboratories to provide segregation and secondary containment of hazardous materials. In general, chemical usage at the NSLS is characterized by small quantities, large variety. A Lab Stewardship program has been initiated to provide oversight of the storage, use, and disposal of hazardous materials and the use of facilities in the user laboratories.

A small room near the roll-up door on the west side of Bldg. 725 has been designated as a waste collection area. Segregation and secondary containment is being provided as needed. The space is one hour fire-rated, has its own supply and exhaust air system that provides 1 cubic foot/min/square foot of floor area, and the electrical devices within the space are rated for "hazardous locations". The storage room conforms to the requirements of NFPA No. 30, "Flammable and Combustible Liquids Code" and to BNL OHS Guide 4.10.2, 2.1.1, and 2.1.0.

3.3.3.6 Ozone Production

In those areas of the X17, X21, and X25 beamlines where the white (unmonochromated) S.R. beam is not contained within a transport pipe, i.e. the experimental areas within the hutches, the lower energy photons will photochemically react with ambient oxygen to form ozone (Ref. 1). Subsequent reactions of ozone with ambient nitrogen oxides may also result in the formation of nitric acid (Ref. 2). To minimize these reactions, the path length of the white beams should be kept to an absolute minimum.

The formation of ozone will be investigated in these and other potential ozone formation (e.g. X17 tunnel) areas during commissioning of the beamlines, using a portable ozone meter. Should the ambient ozone concentrations exceed the OSHA 8 hr. threshold limit value (TLV) of 0.1 ppm or the short term exposure limit (STEL) of 0.3 ppm, two courses of action are available. The first is to allow the ozone to decay naturally to a safe concentration before allowing human entry into that area. Calculations for decay times may be found in Ref. 1. The second is to install activated charcoal air scrubbers (filters) in the immediate vicinity of ozone production. The scrubbed air may be vented back into the volume of the hutch or tunnel. Which above action is taken will depend on the location of ozone production and the frequency of human entry into the area.

3.3.3.7 Cryogenic Hazards

A 3000 gallon liquid nitrogen storage dewar is stationed just outside the loading dock of 725A. Cryogenic piping supplies liquid into the building for general use by all technical personnel. Hazards are the normal ones associated with such facilities: asphyxiation, over-pressure, and cold burns. The asphyxiation hazard is controlled by using oxygen deficiency detectors, which shut off the liquid nitrogen flow, open the roll-up door, and sound warnings both locally and in the NSLS control room, should a potentially hazardous situation develop. The over-pressure hazard is controlled using pressure relief valves and burst disks. The cold burn hazard is addressed by providing appropriate insulated gloves and safety goggles at the filling station, together with a directive to use them in the posted, step-by-step instruction sign. A procedure for testing equipment associated with asphyxiation prevention has been developed, together with the NSLS Safety Officer. The equipment is tested every six months and records of such testing are kept on file.

Prior to construction, the facility design was reviewed by the Cryogenic Safety Committee. Minutes of this meeting appear as Appendix 7.6. All recommendations of the Committee have been carried out.

A closed cycle helium refrigeration system is used with the X-17 superconducting wiggler magnet. The automated system's location is one of low personnel occupancy. Nevertheless, the hazards normally associated with cryogenic facilities are present: asphyxiation, over-pressure, and cold

burns. Asphyxiation protection is provided by local oxygen sensors that will sound an alarm and automatically activate building vent systems. The over-pressure hazard is controlled by pressure relief valves and burst disks. Cold burn protection is provided by isolation of cold surfaces from personnel, and piping of any vented cryogenics to the exterior building space. During system design, safety criteria, as outlined in BNL's Occupational Health and Safety Guide section 5.1.0 nonflammable cryogenic, were followed to assure minimum exposure of cryogenic hazards to personnel.

A procedure for testing equipment associated with asphyxiation prevention has been developed, together with the NSLS Safety Officer. The equipment is tested every six months and records of such testing are kept on file.

The proposed system was reviewed and accepted by BNL's Cryogenic Safety Committee on December 11, 1986. Minutes of this meeting appear as Appendix 7.7. All recommendations of the Committee have been carried out.

3.3.3.8 Environmental Hazards

Floor drains in the Phase I building were designed to discharge into the storm drainage system, whose effluent is ultimately re-charged into the ground water. This design concept was in conformance with laboratory policy at that time. We have since been made aware of the potential problems with this procedure of indiscriminately dumping the floor drain waste into the ground. Therefore, we have revised the floor drain piping to discharge into the sanitary system. In this system, the effluent is monitored (tests for oil, pH, radioactivity, and electrical conductivity are made) and the effluent is processed at the sewage treatment plant before being discharged into a tributary of the Peconic River.

3.3.3.9 Magnetic Field Hazards

The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values and Biological Exposure Indices for 1988-1989 (p. 115) recommends that workers having implanted cardiac pacemakers not be exposed to magnetic fields in excess of 1.0 milli-Tesla (10 Gauss). All areas at the NSLS in which fields exceeding this value may be encountered

will be clearly posted as magnetic field areas in which persons with pacemakers are not permitted.

3.3.4 Emergency Power and Lighting

The power for emergency use is derived from two 75 KW existing diesel generators located in the adjacent building 535 basement. The emergency power supplies power for emergency lights, sump pumps, sewage ejectors and sprinkler air compressor. The emergency load is normally fed from the conventional electric service. Upon failure of normal service, the emergency load will automatically be transferred to the emergency generator supply. When the normal supply is restored the load will automatically transfer back to its normal service. The electric service is considered failed when any phase leg drops below 70% of normal voltage and remains below 70% for one second or longer. Any power dip in voltage that lasts less than one second will not transfer to the emergency circuit. Service is considered returning to normal when voltage on each phase leg reaches 90% of normal voltage. A delay of up to 10 seconds may elapse before the generator picks up the full emergency load.

3.4 Laser Electron Gamma Ray Facility

The Gamma Ray Facility is a small addition to the original NSLS building protruding on the side of the building in the vicinity of beamline X5. The materials of construction for the walls, roof, floor and exterior skin are the same that were used in the original design. The facility consists of a γ -ray laboratory of approximately 1500 square feet, and a computer room and a general purpose room of approximately 300 square feet additional. Above the computer and general purpose rooms there is a small mechanical equipment space. The facility is served by a three ton overhead bridge crane in the laboratory area and a one ton monorail which extends from the X-ray floor into the γ -ray laboratory. Entrance and egress from the facility is from the X-ray floor through a door leading to the General Purpose room and another door leading into the γ -ray laboratory. There is no direct access to the facility from the exterior. All doors are interlocked with key access similar to other experimenters hatches. Adjacent to the door from the laboratory area is an exterior door that leads to an areaway and the outside. Egress around the X-ray Ring - 6 foot aisle is fully described in Section 5.3.5.

The Computer and General Purpose rooms have a raised floor supported on steel stringers and posts. Walls are gypsum wallboard on concrete block. The roof consists of a steel frame over which there is a corrugated metal deck, a rubber insulating sheet and a finish top surface of 20 gauge flat sheet metal. The underside has an acoustic ceiling. The roof of the computer and general purpose space serves as the floor for the mechanical equipment. A railing protects the free edges of the platform which is accessed by a vertical ladder from the X-ray floor. The entire facility has detectors and sprinkler fire protection. The laboratory area, mechanical space, computer and general purpose rooms are tied into the preaction system extending from the X-ray area. Wall mounted fire extinguishers are also in the laboratory area.

A full description of the facility including the hazards and controls for radiation, laser light, cryogenics etc. is given in Section 5. of this report.

3.5 R.F. Extension

The R.F. extension is a small addition to the existing R.F. area and is located in the transformer courtyard area. It is a two story structure of approximately 2300 square feet on the ground floor level and approximately 3,000 square feet at the second floor level. The construction materials for the floors, walls, roof and exterior skin are the same materials specified for the second floor of the original facility. However, due to the close proximity of the existing electrical transformers to the extension, the entire wall facing the transformers is specially prepared. The lower level first floor wall is made up of 10 inch masonry construction and contains no windows. Similarly the second floor wall facing the transformer yard has no windows. This second floor exterior wall is composed of 2" insulated siding, matching the remainder of the building. The interior wall behind the concrete block, or exterior panels and structural steel, poses a two-hour fire rating. Access and egress from the lower level is through a man door or large roll-up door that leads directly to the courtyard and ramp. Another egress from this space is directly into the existing R.F. area. Access and egress from the second floor is into the existing second floor corridor. There is also a door that leads to the roof area from the second floor space. The structural steel frame has a two-hour sprayed-on fireproofing, permitting the construction of a third floor in the future.

Each floor of the addition is protected by a sprinkler system. The first floor has detectors and the sprinkler is tied into the existing preaction fire protection system from the R.F. area. The second floor has no detection system and is tied into the existing second floor wet pipe system.

Since the first floor is intended to be used for receiving and storage, and the second floor use will be open office space, no special hazards are expected to be present.

3.6 Infrared Platform

The Infrared (IR 4) platform is located in the VUV area between beamlines U-1 and U-3, as shown in Fig. 3.1. It consists of a 400 square foot 4" reinforced concrete slab on a structural steel frame. The frame is supported from existing building steel at one end and on 4 inch diameter steel pipe columns at the other end. An open steel stair connects the platform with the VUV floor. The top of the platform is approximately 10'.2" above the VUV floor and headroom clearance to the underside is approximately 9'.2".

A 3' 6" high pipe railing around the platform's perimeter provides for personnel safety. Attached to the railing is a steel kick plate and fine wire mesh screen that protects occupants and equipment below the platform from injury and damage due to accidentally dropped objects.

Because the platform is in the VUV area there are no special environmental or fire protection requirements. However, additional sprinkler heads were installed below the platform to protect those areas that were shaded from the VUV's sprinkler system.

4. EXPERIMENTAL AREAS - INSERTION DEVICE BEAMLINES

4.1 Soft X-ray Undulators

4.1.1 Introduction

This section of the S.A.R. covers the Phase II soft X-ray undulators, insertion devices on the X-ray Ring with fundamental wavelengths in the 1 - 10 nm range. The radiation from these devices is both softer and brighter than the radiation from a bending magnet port on the X-ray Ring and requires a different philosophy with respect to hazards and controls. Two examples of such devices are the mini-undulator, planned to be installed on port X-13 and the Soft X-ray Undulator (SXU), planned to be installed on port X-1. Since the SXU is the brighter of the devices which otherwise have comparable spatial and spectral radiation characteristics, we will use the SXU as the prototypical soft X-ray undulator.

An undulator is a device producing alternating magnetic fields usually produced by permanent magnets. When the electron beam threads the field, it gently "undulates" and produces synchrotron radiation. The ratio of the maximum deflection angle to the synchrotron radiation opening angle is the magnetic deflection parameter K . For values of K less than or comparable to unity, the spectrum produced has sharp peaks at selected wavelengths. The flux is collimated both horizontally and vertically leading to the primary advantage an undulator has over a bending magnet, namely increased brightness (flux / solid angle / source area) at these harmonic wavelengths. As K is increased, the peaks begin to disappear and the spectrum approaches that of a bending magnet with field equal to the undulator peak field. At large values of K , the device is called a wiggler. As an example, Fig. 4.1 shows the SXU total output at the relatively small K value of 0.5. Fig. 4.2 shows the output at the maximum K value of 2.4, where the fundamental has shifted toward softer wavelengths, but the many higher harmonics make the output of the device look rather like a bending magnet spectrum. The SXU parameters are listed below, based on X-ray Ring design parameters of 2.5 GeV, 500 mA.

Period	8.0 cm
Number of periods	35
Magnetic material	samarium cobalt
Pole material	steel
Range of K	0.5 - 2.4
Range of fundamental	1.9 - 6.0 nm (0.2 - 0.6 keV)
Peak magnetic field	0.3 T
Maximum power	0.7 kW
Maximum power density	2.5 kW / mrad ²

4.1.2. Device and Beamline Operation

The K value of the SXU is controlled by changing the distance between two beams, each bearing 140 samarium cobalt permanent magnets. The beams are above and below the storage ring vacuum chamber. The magnetic gap can be varied from about 32 to 80 mm. The gap is changed remotely by computer-driven stepping motors. There are small electromagnets built into the ends of the undulator to correct for any steering error introduced by the undulator. The gap spacing is under the control of the control room.

The front ends of the undulator beamlines are similar to the bending magnet port front ends with a photon mask, UHV valve, fast valve and safety shutter. The safety shutters are not water cooled, and thus are not capable of taking the undulator beam, so the photon mask is interlocked to close whenever the safety shutter is down. A set of beam defining apertures in the front end is driven by stepping motors and is capable of absorbing the full undulator output. A beam position monitor in the front end senses the horizontal and vertical position of the photon beam. This information is fed back to the trim magnets on either side of the undulator for closed orbit correction to keep the beam position fixed.

Outside the shield wall, the beam undergoes at least one glancing incidence reflection with a graze angle of about 40 mrad. This acts as a low pass filter and allows the experiment to be set up outside the bremsstrahlung cone. Typical experiments done on the undulator include soft x-ray spectroscopy and soft x-ray imaging. Almost all of these experiments are done in an ultrahigh vacuum environment with the experimental station vacuum contiguous with storage ring vacuum. As will be discussed below, a radiation hutch is not required to do these experiments safely.

4.1.3 Hazards and Controls

4.1.3.1 Device Hazard

The primary hazard associated with the undulator is that of a moving 1700 pound object. For testing purposes, it is necessary for personnel to be present when the undulator is moving. The hazard is controlled by a plexiglas cover over the device to keep fingers out. The samarium cobalt magnets are considered toxic and direct skin contact must be avoided. The cover will prevent access to the magnets. The magnet blocks present no unusual fire hazard, according to a review by the Safety and Environmental Protection Division of the Material Safety Data Sheet on samarium cobalt alloys; see Appendix 7.2.

The moving undulator also presents the hazard of crushing the storage ring vacuum chamber if the gap is closed too far. Hard stops on the chamber, redundant optical limit switches and software limits are present to keep this from happening.

4.1.3.2 Electrical Hazards

Both the insertion device and the experimental beamline present no unusual electrical hazards. Electrical safety can be treated identically to Phase I devices and beamlines.

4.1.3.3. Cryogenic Hazard

None.

4.1.3.4 Occupational Health Hazards

Any occupational health hazards specific to a beamline looking at undulator radiation would be addressed at the Beamline Safety Review required before any beamline can be declared operational at the NSLS.

4.1.3.5 Visible Light Hazard

The peak intensity in the visible coming from the SXU is higher than that coming from an X-ray Ring bending magnet. Consider the worst-case (highest K and storage ring current) intensity distribution of 500 nm light just outside the shield wall: The peak intensity is about 9×10^{12} photons/s/.1% B.W./mrad², compared to about 8×10^{11} photons/s/.1% B.W./mrad² from an x-ray bend. The intensity falls to below that of the bending magnet within a few millimeters of the horizontal center of the visible light distribution. (Extra lobes of visible light present, typical of the soft output of the undulator, are only about 10% of the intensity on-axis.) The total output in the visible is under a milliwatt. Thus the output power and divergence of the visible light is comparable to that of a Class II laser and the usual precautions taken for visible light hazard at X-ray Ring bending magnet ports will apply. These include not allowing any specular reflections visible through viewports, covering all viewports, and posting warning signs on the covers.

4.1.3.6 Radiation Hazards

Inspection of Fig. 4.1 and 4.2 shows that the hardest spectrum occurs when $K = 2.4$. We will use this worst case in considering possible radiation hazards from the SXU. At this relatively high value of K, we can ignore the structure in the spectrum and consider the radiation as if it were coming from 70 dipole magnets (one for each pole of the undulator) of critical energy 1.3 keV, corresponding to the critical energy of the peak magnetic field of 0.3 T. This compares favorably to the 5 keV critical energy of X-ray Ring bends and is not that different from the 0.5 keV critical energy of UV ring bending magnets. The full horizontal width of the radiation is under one mrad.

The scattered radiation hazard should be negligible. The most transparent element in a typical uhv beamline is the convolutions in a

Fig. 4.1

Fig. 4.2

vacuum bellows, but even these thin bellows transmit less than 10^{-11} of the incident 10 keV flux. Experiments contained completely in a uhv environment will thus not need to be done in a radiation hutch. Radiation surveys of the beamline must of course be made, especially if there is any change in beamline configuration.

There is one class of experiment that cannot be contained in a uhv environment, namely biological imaging experiments on living cells and tissue cultures. For such experiments where the beam must be brought out into the ambient environment through a (very) thin window, the danger of a skin burn from the soft radiation exists. This hazard is dealt with by requiring the experiment to be done inside a no-hands environment. Fig. 4.3 displays calculations done for the experimental flux from the mini-undulator in such an experiment and S&EP Division representative Norman Rohrig's assessment of the interlock requirements. Note that the radiation flux from the full SXU is only 4 times that from the mini-undulator and the arguments presented in Fig. 4.3 are still valid.

The potential for higher bremsstrahlung exposure on a beamline looking at 10 meters of straight section vacuum pipe is greater than on a bending magnet beamline which only sees a few centimeters of electron beam orbit. The Phase I bremsstrahlung shielding requirements took this situation into account, however, and the required shielding should be adequate. Nevertheless, radiation monitoring will be done periodically to verify the placement and amount of shielding.

4.1.3.7. Beam Heating Hazards

The power density in the undulator beam is sufficiently high to melt uncooled surfaces that the beam hits, especially at normal incidence. Fortunately, the total power is moderate and can safely be removed by conventional water cooling methods. Calculations and e-beam welder simulations have verified that the worst case power density from the SXU will not overheat the water-cooled photon mask, which can safely be used as a photon beam shutter. The Phase II insertion device and exit chambers have been modified to be passively safe for the SXU worst-case beam. The front ends and beamlines are similarly designed so that it is impossible for the beam to impinge on uncooled surfaces, given the worst case origin of 2.5 mm

x 13 mm offset from the nominal source point. Of course if the water flow fails, the storage ring beam is automatically dumped.

Fig. 4.3A

APPENDIX

Calculation of Hard X-ray Flux

In order to see whether a hutch is necessary for the X-17T beamline, we must calculate the hard x-ray flux at the experimental station. We take the worst case:

minimum undulator gap (31mm)
maximum stored beam (250 mA)
maximum pinhole size (0.5 mm)
monochromator set to zero order
exit slit wide open
no contamination barrier

We can now compute the flux, binned by energy.

<u>Energy bin</u> (keV)	<u>Undulator output</u> (photons/s)	<u>Mirror</u> <u>Reflectance</u>	<u>Pinhole</u> <u>Acceptance</u>	<u>Monochromator</u> <u>Efficiency</u>	<u>Flux at</u> <u>Expt.</u>
3 - 4	2.6×10^{16}	4.0×10^{-4}	.01	11×10^{-4}	110 $\times 10^6$
4 - 5	1.5×10^{16}	1.2×10^{-4}	.01	4×10^{-4}	7 $\times 10^6$
5 - 6	0.9×10^{16}	0.6×10^{-4}	.01	2×10^{-4}	1.1 $\times 10^6$
6 - 7	0.6×10^{16}	0.3×10^{-4}	.01	1.3×10^{-4}	0.2 $\times 10^6$
7 - 8	0.4×10^{16}	0.15×10^{-4}	.01	0.8×10^{-4}	0.05 $\times 10^6$
8 - 10	0.4×10^{16}	0.08×10^{-4}	.01	0.5×10^{-4}	0.017 $\times 10^6$

The worst case total flux above 6 keV is less than the 10^6 photons/s, which S&EP Division representative Norman Rohrig stated was acceptable for hutchless operation. As for the larger flux near 3 keV, note that the thinnest vacuum envelope we have is the 0.006" stainless steel convolutions on our bellows--these transmit only 10^{-16} of the incident 4 keV photons.

The other possible contribution to the hard x-ray flux could come from the fringe fields of the bending magnet. But with our front end collimation,

Fig. 4.3A continued

we accept less than 1 mrad of the contribution from the nearer bending magnet. According to calculations of Andy Sandorfi (LEGS Technical Note, August 13, 1984, "The Synchrotron Power and Resulting Stress on the 0° Window"), the critical energy there is less than 1 keV, so the contribution above 6 keV should not be appreciable.

As a final point, similar undulators at the Photon Factory and SSRL have been approved for hutchless operation.

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: June 2, 1986

TO: H. Rarback

FROM: N. Rohrig

SUBJECT: Interlock requirement for
X-17T Undulator

I have considered the available flux from the undulator being installed temporarily at X-17 which will pass through an x-ray mirror followed by a monochromator followed by a zone plate 100 μm in diameter which focuses desired radiation through a 20 μm diameter pin hole. Design objectives are to focus 10^7 photons/sec at 400 eV through this aperture. Following this you will place a sample and detector for x-ray imaging near the aperture and you are willing to enclose this in a lucite box. All other experiments on this line will be performed in vacuum chambers. We have agreed that the interior of this small box ($< 1 \text{ ft}^3$) be treated as a High Radiation Area (see Safety Manual Guide 3.4.0 enclosed) with a simple interlock to close the shutter when the box is opened or removed.

An x-ray mirror located 14.6 m from the source bends the low energy beam 80 mrad into a monochromator located 6.8 m further downstream. Your sample will be about 2.5 m past the monochromator. The intended radiation at 400 eV will not pass through the dead layer of skin. At 1 keV the dose conversion factor at a depth of 0.07 mm in tissue is about 10^{-10} that at 2 keV per unit flux. For the April 29 beam line review, you estimated the worst case flux at the experiment from the undulator based on your understanding of the mirror, monochromator, and pinhole. The following table shows dose rates at depth of 1 cm and 0.07 mm based on these fluxes averaged over 1 cm^2 .

Fig. 4.3B continued

H. Rarback

2

June 2, 1986

<u>Energy bin (keV)</u>	<u>Flux at expt. (photons/sec)</u>	<u>Shallow dose index (mrem/hr)</u>	<u>Deep dose index (mrem/hr)</u>
3-4	1.1×10^8	1.3×10^6	$< 5 \times 10^{-27}$
4-5	7×10^6	6×10^4	7×10^{-13}
5-6	1.1×10^6	7×10^3	1×10^{-6}
6-7	2×10^5	1×10^3	2×10^{-3}
7-8	5×10^4	2×10^2	2×10^{-2}
8-10	1.7×10^4	6×10^1	0.5
		$> 10^6$ mrem/hr	< 1 mrem/hr

Flux from the fringe field at the entrance to the dipole as you point out is smaller than that from the undulator and should be collimated out of the beam. Clearly these calculated dose rates are a) not life threatening so a hutch is not required but b) might result in a skin burn if the hand was held in the beam. Thus, the agreed to provisions are appropriate.

NR:stc

Copy to: T. Dickinson
R. Heese
R. Klaffky
C. Weilandics
O. White

Enclosure

4.2 High-Energy High-Power Superconducting Wiggler Beamlines

4.2.1 Introduction

The generic class of beamlines utilizing synchrotron radiation from high-energy high-power superconducting wiggler magnets can be represented by the X17 beamline at the NSLS. Any future magnet of this type will probably have a comparable high energy spectra and equivalent power density. Thus, X17 will be the model used for this class of beamline. The essential parameters of the X17 superconducting wiggler magnet and its spectrum are given in Appendix 7.4., and in Table 4.1.

There are two primary features which distinguish the radiation from the superconducting wiggler (SUW) from that of a bending magnet or other insertion devices (e.g. undulators and permanent magnet wigglers), the higher critical energy, and the large horizontal divergence of the high-power radiation fan. With regard to the problem of personnel radiation protection, the significantly higher critical energy of the spectrum due to the high magnetic field gives a much harder photon spectrum. Fig. 4.4 gives a comparison between the X17 spectrum and that from an NSLS bending magnet. To adequately shield against the higher energy photons requires a significantly greater amount of lead and steel. New approaches to hutch design have resulted, and the concept of enclosing the entire beamline in a radiation shielding tunnel (actually a long hutch) has been implemented.

The shielding calculations and design have been carried out for a combination of electron energy (2.528 GeV) and wiggler field (5.22 Tesla) which yields a critical energy of 22.2 keV. The electron beam current was taken to be 250 mA. Because the radiation leakage levels will depend strongly on the critical energy, operation of the wiggler such that the critical energy exceeds 22.2 keV is prohibited without review and approval by the BNL Safety Committee.

In addition to the high-energy spectrum, the wiggler produces a large total radiated power. It has 7 poles, two at half field and 5 at full field. With a critical energy of 22.2 keV at 2.528 GeV ring energy, the total power radiated by the device at a ring current of 250 mA is about 13.2 kilowatts into a fan of 41 mrad. The power density which must be dealt with at full operating electron current is thus about 1.77 kW/mrad² or 1.77

kW/cm² at a distance of 10 meters from the source. In order to properly split, aperture, and stop the beam, it has been necessary to carry out an extensive finite-element analysis of the components in order to arrive at a final design. The complete summary of this phase of the X17 project is given in Appendix 7.3, in the paper by Ulc and Sharma. Note that the power density used for the Ulc and Sharma thermal analysis was based on a ring current of 500 mA and 6 Tesla wiggler field, thus their peak power densities are greater than those anticipated for the present configuration.

The detailed description of the X17 beamline, necessary to understand the following sections on radiation shielding, is included as Appendix 7.4, in the paper by Thomlinson, et al.

The X17 beamport contains no new hazards, with reference to the Phase I bending magnet lines, in the areas of electrical hazards, visible light hazards (there are no view ports which can be looked into by naked eye), or experimental operations. The safety system hardware, the operational philosophy, and the implementation are the same as addressed in the Phase I SAR (BNL 51584). However, as indicated above, there are new concerns which must be addressed in this report in the areas of Radiation Hazard 4.2.3, Occupational Health Hazards (Ozone Production) 3.3.3.6, Accident Assessment 4.2.2, and Cryogenic Magnet Safety 3.3.3.7.

The X17 beamport is divided into three branches, only two of which (B and C) are presently planned to be brought out of the shield wall. The B and C programs will be able to run independently. The smaller "C" line will have a variable horizontal width of 0-3 mrad. It is being instrumented for materials sciences at high pressure. No unusual hazards will exist on that program. The central "B" beam will be 5 mrad in the horizontal. It will be used in a tandem fashion by two programs. The first hutch will contain the X17B1 materials sciences program. A variety of materials sciences experiments will be carried out in that facility, very similar to programs already existing on bending magnet beamlines. When that hutch is not on line, it will be interlocked in a secured mode, and the beam will travel through a beam transport pipe into the X17B2 Synchrotron Medical Research Facility (SMERF). SMERF will be used in the future for medical research on human coronary angiography, human computed tomography of the cerebrum, cancer radiotherapy experiments, and possibly human radiosurgery. Since the SMERF programs involve human research, a complete and separate SAR review of

the human studies safety system as well as tandem operation with X17B1 will be done in the future. Thus X17B2 operation and shielding will not be discussed further in this present SAR.

4.2.2 Accident Assessment

From an experimenter's viewpoint, the operation of X17 will be very similar to normal bending magnet lines. The same safety procedures will be used. The only visible difference will be the design and construction of the X-ray shielding for the hutch and tunnel. In fact, the interlocks are more complex due to the need to interlock the magnet operation with the physical positions of apertures and the operating conditions of the storage ring in order to prevent accidental exposure of the vacuum vessels to extreme high thermal loading. However, with regard to prevention of radiation accidents, the same analysis as covered in the Phase I SAR (BNL 51584) holds for these types of beamlines and safety systems.

The increased power in the photon beams, besides increasing the required thicknesses of shielding, necessitates a more complex interlock system to prevent hardware damage which could lead to expensive, long periods of facility downtime. The beam steering and monitoring of the electron beam have been designed to allow only those orbits which are safe for the machine hardware. In addition, the ring vacuum exit chambers have been completely redesigned and replaced to allow passive safety against structural failures if targeted briefly by the direct photon beams. Enough time is allowed for the sensing systems to dump the beam without severe damage resulting. The superconducting wiggler magnet bore tube has also been redesigned to allow passively safe operation. The beamline will have one or more beam position monitors for the photon beam. Under normal operation, they will sense the beam position and feed back a signal to the ring to maintain a stable position of the photon beam. Failure of the system to track or find the beam will cause an electron beam dump.

With the ring at injection energy, the magnetic field will have to be at a minimum value (to be determined) for injection to be possible. If the field is non-zero, the system will have to insure that the high vacuum valve and mask are opened, and that the front end photon beam shutters and safety shutters are in place. The dipole radiation water cooled mask cannot be allowed to see wiggler radiation. The safety shutters are not water-cooled

on this beamline, so whenever they are closed, it is essential to have the SUW photon shutters in place. Any action requiring the closure of the safety shutters must be sequenced to the closure of the photon shutters. In addition, there is a second set of personnel safety shutters downstream. They are designed to prevent cross-talk of scattered wiggler radiation between the X17B and X17C lines. It is thus necessary to have the front end photon shutters and the downstream safety shutters closed for a given beamline in order to have hutch entry for white beam experiments.

For some future experiments there will be a monochromator in the central (X17B) beamline. When it is used, it will absorb the white radiation power. Entry into the X17B1 hutch will then be allowed with only the downstream bremsstrahlung shutter closed, in effect acting like the photon shutter on normal bending magnet lines. The front end photon shutters will not be closed, thus allowing the monochromator optics to remain bathed in radiation and therefore isothermal.

4.2.3 Radiation Hazard

4.2.3.1 Shielding Requirements

As noted in the above section, the much harder photon spectrum produced by the high magnetic field of the SUW necessitates a new and more comprehensive level of personnel radiation protection in order to meet the requirements of DOE Order S800.11 for radiation levels of less than or equal to 0.5 mRem/hr for continuously-occupied areas and a non-radiation worker dose of 100 mRem/yr. Using PHOTON (Ref. 3), a FORTRAN program which calculates transmitted and scattered spectra as well as radiation levels as a synchrotron beam passes through sequential filters or walls, a detailed analysis was made of the radiation levels at all scattering points along the X17 beamline from the SUW to the rear of the X17B1 hutch. Shield walls composed of lead and steel (in addition to cement in certain areas) were introduced into the calculations to determine the effects they had upon reducing these radiation levels.

The final determination made was that the ring chamber and front end elements must be shielded with an additional 1/8" of lead sheet. The scatter shielding which the concrete shield wall would provide was not considered adequate since this wall is primarily for neutron shielding.

The entire beamline downstream of the sawtooth must be surrounded by a series of panels made of a composite of 1/8" steel + 1/4" lead + 1/8" steel. These panels are assembled as a transport hutch from the sawtooth downstream to the beamline apertures and as hutches for the X17B1 and X17C experimental areas. Personnel are excluded from being in these enclosures while they are operational. The B1 transport pipe through the C hutch must be covered with 1/4" Pb (this pipe contains no scatter sources in contrast to the hutches) to allow access to X17C while X17B is operational.

The results of the PHOTON calculations described above are presented diagrammatically in Fig. 4.5 to 4.9. In all cases the dose surface used was ICRU4, an artificial unit density tissue composed of $H = 0.1010$, $C = 0.1110$, $N = 0.0260$ and $O = 0.7620$ as mass fractions (Ref. 4). All doses given are in millirads per hour and, unless stated, distance from scatterer to dose surface is 1 meter. The front end valves given in Figs. 4.5 and 4.6 show calculated radiation doses outside the shield wall not exceeding 2.1×10^{-3} mrad/hr., well under the maximum level of 0.5 mRem/hr. In a worst case scenario of an exposure consisting of 8 hrs/day, 5 days/wk, 40 wks/yr, the calculated 3.36 mrad/yr dose is also well under the 100 mRem/yr non-radiation worker dose. Similar low doses are calculated outside the transport hutch and the X17C hutch (when beam is allowed to enter X17C). Slightly higher doses are calculated outside the X17B1 hutch as a result of scatter of a white beam from a silicon crystal or from the Cu backstop. The final determination of total annual dose will have to await actual beamline operation, and corrective measures will be made if necessary.

4.2.3.2 Operation of Tandem Hutches

A) Normal Operation

Opening the shutters for B1, or C operation requires that the tunnel be secured and interlocked. The B1 and C shutters can be opened when the respective hutches have been secured and interlocked. Opening the shutter for B1 operations also requires that the backstop has been locked in the IN position.

The B1 hutch can operate in two modes:

- 1) White beam mode: The B front end safety shutter and the B beamline safety shutter operate in tandem. Any action requiring the cycling of the safety shutters must be sequenced to the closure of the front end photon shutters. Since the bremsstrahlung is removed by the front end safety shutter, the beamline safety shutter plays a secondary role in reducing the scatter from the C beamline into the B beamline.
- 2) Monochromatic beam mode: The B front end safety shutter can be opened without the B beamline safety shutter also opening because the power of the wiggler beam has been deposited in the monochromator system. This allows B1 hutch entry without interrupting the beam onto the B1 monochromator in the transport hutch. This improves the performance of the monochromating system.

The C hutch operates only in white beam mode. This beamline also has a C front end safety shutter and a C beamline safety shutter which operate in tandem. The seemingly redundant beamline safety shutter reduces cross-talk from the B beamline and allows a future upgrade to monochromatic beam mode similar to the B1 program.

The scatter shielding surrounding the B1 transport pipe through the C hutch is designed be such that access to the X17C hutch is allowed when the beam into X17B1 or X17B2 is present. The shielding covering this pipe is the 1/4" lead plus 3/16" (nominal) steel of the vacuum pipe. During operation there are no sources of scatter present in the pipe. The nearest sources of scatter are 1) the X17B1 monochromator approximately 3 meters upstream 2) the beamline apertures in the tunnel approximately 4 meters upstream, and 3) the beryllium window assembly on the downstream end of the X17B transport pipe in the X17B1 hutch.

The beamline aperture or X17B monochromator scatter cannot enter the X17C hutch when the X17C beamline safety shutter (bremsstrahlung) is closed. This is due to the fact that that X17C shutter block extends nearly to the edge of the X17B beam. Any scatter from the apertures is then contained within the X17B transport pipe or strikes the pipe at a small angle and is absorbed by the large effective path length in the steel and lead. When the

X17B shutter is closed, any scatter from the aperture or monochromator area cannot enter the X17B hutch. Also, since the X17B transport pipe through the C hutch has a 1/4" lead or lead equivalent shield, any scatter within the C hutch cannot enter the B1 hutch.

The X17B1 beryllium window is a much closer source of scatter to personnel present in the X17C hutch. The estimated position of the beryllium window assembly results in an expected minimal dose rate back through the steel and lead at 45° through the pipe ($\sim 3.4 \times 10^{-3}$ mrad/hr).

B) Accidents

The B1 transport pipe through the C hutch is the only section of the beamline where personnel may approach any of the beam transport which is not contained within a secured enclosure or interlocked hutch while beam is present. Thus additional calculations were performed to ensure that the shielding is sufficient for accidents involving this section. The expected worst accidents involving the transport pipe result in scatter through the length of that pipe. The first is an accidental misalignment of the pipe in which the beam grazes the side of the pipe. The pipe should be easily surveyed so that the beam cannot strike the sides of the pipe. If such a strike occurs, the angle of incidence is small (< 1 radian) so as not to pose a radiation threat. This scatter is attenuated by the steel and lead shielding around the pipe. A calculation of the scattered dose resulting from a 4 mradian wide beam striking the pipe where the ICRU4 dose surface is 150 mm from the pipe gives a value of .178 mrad/hr. The most likely accident is if the transport pipe is filled with air and further, this failure of vacuum is not sensed immediately. A calculation was performed to estimate the absorbed dose arising from a line source of scattering from a 2 meter column of air in the pipe with the ICRU4 dose surface 150 mm from the pipe center, i.e., 1 meter from each end. The dose delivered was found to be 1.0×10^{-2} mrad/hr (Fig. 4.9).

Table 4.1: Essential Parameters of X17 SUW

Device Parameters

Pole - full field	5
- half field	2
Period length	17.4 cm
Gap	3.2 cm
Magnetic field	5.22 Tesla

Operational Parameters

Maximum wiggler field	5.22 Tesla
Ring energy	2.528 GeV
Min. bending radius	1.615 meters
Critical energy (E_c)	22.2 keV
Deflection parameter K	84.47
Horizontal opening angle on-axis	41.0 mrad
Vertically integrated power density	2.14 W/mrad-mA
Total power	52.8 W/mA

Fig. 4.4

PERSONNEL EXCLUDED DURING OPERATION

1" LEAD SHIELDING (---)

RING CONDITIONS: 2.528 GeV 250 mA 522T FIELD ($E_c = 22.18$ keV)

5 POLES

2.61T ($E_c = 11.09$ keV)

2 POLES

Scattered Dose Values - Source to Dipole

Fig. 4.5

RING CONDITIONS: 2.528 GeV 250 mA 522 T - 5 poles ($E_c = 22.18$ keV)
 2.61 T - 2 poles ($E_c = 11.09$ keV)

Scattered Dose Values - Dipole to Shield Wall

Fig. 4.6

Scattered Dose Values - Shield Wall to Transport Hutch

Fig. 4.7

PERSONNEL EXCLUDED DURING OPERATION

RING CONDITIONS: 2.528 GeV 250mA 5.22 T Spokes ($E_c = 22.18 \text{ keV}$) X17 Tunnel
 2.61 T 2 poles ($E_c = 11.09 \text{ keV}$) Dose Calculations

Scattered Dose Values - Transport Hutch to C Hutch

Fig. 4.8

RING CONDITIONS: 2.528 GeV 250mA
 5.22T 5poles ($E_c = 22.18 \text{ keV}$)
 2.61T 2poles

X17C + X17B1 Hatches
 DOSE CALCULATIONS
 Dose values in millirads/hour

Scattered Dose Values - B and C Hatches

Fig. 4.9

4.3 Hybrid Wiggler Beamlines - X21/X25

4.3.1 Introduction

The class of beamlines utilizing synchrotron radiation from permanent magnet hybrid wigglers are represented by X21 and X25. These radiation sources produce spectra which are similar to those produced by a standard bend magnet, but amplified by a factor of 30 due to the number of poles in the wiggler, each pole acting as one effective bend magnet. When operated at closed gap, these wiggler magnets will produce an on-axis field of 1.1 Tesla, resulting in a peak critical energy of 4.57 keV when the storage ring is operated at 2.5 GeV.

The horizontal opening angle of the wiggler radiation is 5.0 mrad at 2.5 GeV. The critical energy of the radiation, however, is not constant across the fan. Only at the center of the fan does it reach its peak value; at 80% of the distance to the edges of the fan from the center (i.e., at ± 2.0 mrad relative to the center line at 2.5 GeV), the critical energy falls to 60% of its peak value. For larger angular excursions, the critical energy falls precipitously, to a value of zero at the edges of the horizontal fan. The radiation shielding calculations, which were performed using the PHOTON program (Ref. 3), were based on a model spectrum which used the appropriate peak critical energy (4.57 keV at 2.5 GeV) over a horizontal fan covering 80% of the full angular opening (4.0 mrad at 2.5 GeV), and zero critical energy (i.e., no x-ray intensity) over the extremal 20% of the fan.

With 250 mA of machine current (assumed in the calculations), the total power radiated from this wiggler source is 2.15 kW at 2.5 GeV. 90% of the total power emanates within the central 80% of the horizontal angular opening used in the calculations. The 10% of the power radiated into the extremal 20% of the fan is associated with a relatively soft x-ray spectrum and should pose no significant hazard.

Three sections of the beamline were treated separately in the calculations: (1) the front end, or portion on the machine side of the concrete shield wall, (2) the transport section, or components between the shield wall and the hutch (e.g., mirror and monochromator tanks, beampipes, windows and filters), and (3) the hutch. All radiation doses were calculated at unit density ICRU4 (Ref. 4) artificial tissue surface located

perpendicular to the scatter source. It was also assumed that the full, unattenuated x-ray spectrum was incident on a particular scatter source.

The details of the calculations are presented in the next three sections; the conclusions are summarized here. For the front end, the existing 12 inch thick cement wall is sufficient shielding, with the worst case radiation leakage calculated to be below 10^{-8} mrads/hr. Where 12 inches of 5% borated polyethylene are substituted for cement, the calculations predict leakage below 0.1 mrads/hr. For the transport section, the calculations were performed for various shield walls surrounding representative scatterers which will exist in the white beam path. For scatter off carbon filters, beryllium windows, lead masks, and helium gas, the minimum shielding to be used is 3/8 inch thick stainless steel or 1/16 inch thick lead. For these cases, the worst radiation leakage is calculated to be below 0.5 mrads/hr. For scatter off silicon crystals and copper masks, the calculated leakage through these shield walls is above 0.5 mrads/hr but below 10 mrads/hr. For these cases, a radiation survey will be used to determine if an additional 1/16 inch thickness of lead shielding is required to bring the leakage level below 0.5 mrads/hr. Finally, if the white beam will enter the hutch, then its walls and roof must be lined with at least a 1/16 inch thickness of lead, to ensure a calculated leakage below 0.5 mrads/hr. The doses expected through the chosen shieldings for the transport and hutch sections are highlighted with boxes in Tables 4.2 and 4.3.

4.3.2 Front End

The calculations show that the cement of 12 inches thickness which composes the shield wall is more than adequate radiation shielding, with the worst dose being $<1 \times 10^{-8}$ mrads/hr at 2.5 GeV, resulting from complete scatter of the white beam off a copper aperture. Where 5% borated polyethylene of 12 inches thickness has been substituted for the cement, the calculations predict the corresponding dose to be <0.1 mrads/hr at 2.5 GeV. These calculations include the stainless steel vacuum chamber of 1/8 inch thickness as part of the shield wall.

4.3.3 Transport Section

Compared with a standard bend magnet beamline, requisite radiation shielding of transport section components of a hybrid wiggler beamline is unusual only at locations where the white beam encounters matter. Objects placed in the path of the white beam include carbon filters of 0.0066 inch total thickness, 0.010 inch thick beryllium windows, silicon crystals, copper masks, lead masks, and helium gas at 1 atmosphere pressure. Table 4.2 summarizes PHOTON calculations (Ref. 3) for the expected normal incidence ICRU4 doses through various shield walls at 4 inches away from the scatter source, assumed to be a point. These represent the worst case doses, since 4 inches is the closest distance of any shield wall to a possible scatter source, and most scatter sources are not point-like but extended. The dose falls inversely with the square of the distance from the source point. The doses due to scatter from helium gas assume scatter from a 1 meter length of 1 atmosphere gas condensed down to a point, and should be considered as overestimated and simply indicative of the expected order of magnitude.

For all cases, stainless steel of up to 1/8 inch thickness, (e.g., the walls of beam transport tubes, bellows, and vacuum chambers), at 4 inches from the scatter point, should be considered to be inadequate shielding, and therefore appropriate only when the relevant section is evacuated. An additional 1/16 inch thickness of lead will provide enough shielding at 2.5 GeV, except perhaps for scatter off silicon, where the required lead thickness may be 1/8 inch, pending survey. Stainless steel of thickness 3/8 inch should be appropriate except perhaps for scatter off silicon, copper and lead, in which case an additional 1/16 inch of lead may be required, pending survey. Stainless steel of thickness 3/4 inch should be appropriate in all cases. The shielding in areas where the calculated doses are borderline should be finalized following a survey.

4.3.4 Hutch

Hutch shielding in excess of that for hatches used on standard bend magnet beamlines (1/8 inch thick steel) is necessary only if the white beam will enter the hutch. In the hutch, the white beam could be incident on beryllium, 1 atmosphere air, silicon, copper, lead, or any object a user places in the beam. Of the likely objects to be placed in the beam, calculations show that the worst case scatter would probably occur off a

thick silicon crystal. Assuming normal incidence on an ICRU4 surface at 0.6 meter from the silicon scatter source, 1/8 inch of steel shielding is insufficient, but 1/8 inch of steel backed by 1/16 inch of lead will suffice and will be used (Table 4.3). Additionally, 2 inches of cement, a possible component of a hutch wall, may be inadequate at 2.5 GeV but will suffice when backed by 1/16 inch of lead. 1/16 inch of lead alone is sufficient shielding at 2.5 GeV. Where lead glass is used for windows, 1/16 inch lead equivalent is suggested at 2.5 GeV.

TABLE 4.2 - TRANSPORT SECTION SHIELDING

2.5 GeV, 250 mA, 4 horizontal mrad, E = 4.57 keV, 4 inches from scatterer

c

Shield Wall

Scatterer	1/8" Stainless Steel	3/8" Stainless Steel	3/4" Stainless Steel	1/8" Stainless Steel + 1/16" Lead	1/8" Stainless Steel + 1/8" Lead	3/8" Stainless Steel + 1/16" Lead
0.0066" carbon	64 mrads/hr	0.074 mrads/hr	0.00021 mrads/hr	0.0070 mrads/hr	0.000037 mrads/hr	0.00018 mrads/hr
0.010" beryllium	77	0.089	0.00025	0.0084	0.000044	0.00022
thick silicon	4800	8.6	0.029	0.89	0.0053	0.025
thick copper	810	2.1	0.0092	0.24	0.0017	0.0077
thick lead	190	0.45	0.0012	0.044	0.00018	0.0010
1 atm. helium gas (1 meter length)	33	0.038	0.00011	0.0036	0.000019	0.000094

Scatterer	1/16" Stainless Steel	1/16" Lead	1/8" Lead	1/16" Stainless Steel + 1/16" Lead	1/16" Stainless Steel + 1/8" Lead
0.0066" carbon	1700 mrads/hr	0.064 mrads/hr	0.00018 mrads/hr	0.020 mrads/hr	0.000080 mrads/hr
0.010" beryllium	2000	0.076	0.00021	0.024	0.000096
thick silicon	86000	7.5	0.025	2.5	0.011
thick copper	12000	1.8	0.0077	0.64	0.0036
thick lead	2900	0.39	0.00099	0.13	0.00042
1 atm. helium gas (1 meter length)	870	0.033	0.00093	0.010	0.000041

TABLE 4.3 - HUTCH SHIELDING
250 mA 0.6 meter from silicon scatterer

<u>Shield Wall</u>	<u>2.5 GeV, 4 horiz.mrad, E = 4.57 keV</u> c
1/8" Steel	140 mrads/hr
1/16" Lead	0.23 mrads/hr
1/8" Lead	0.00078 mrads/hr
1/8" Steel + 1/16 Lead	0.027 mrads/hr
2" Cement	7.7 mrads/hr
2" Cement + 1/16" Lead	0.0037 mrads/hr

5. LASER ELECTRON GAMMA SOURCE - LEGS

5.1 Introduction and description of LEGS(X5)

The photon source on the 0° port of X-ray Ring dipole X1BM1, designated as user port X5, is referred to as the Laser-Electron-Gamma-Source, or simply LEGS. This line is operated by the Physics Department at BNL. Many safety considerations for this line are identical to those of a standard x-ray beamline and have already been covered in the NSLS Safety Analysis Report (BNL 51584). This section will address principally those areas in which the operating characteristics of LEGS differ from a standard dipole-source beamline.

As the name 'LEGS' implies, this source does not use synchrotron light for scientific research. Rather, laser light is reflected into the injection straight section of the X-ray Ring where it can collide head on with electrons travelling in the opposite direction. Almost all of the photons that interact scatter back through nearly 180° and are boosted up in energy to become γ -rays. The kinematics are defined in Fig. 5.1. Specifically, the energy of the backscattered photon is given by

$$E = \frac{4\gamma^2 \epsilon_\ell}{1 + \frac{4\gamma \epsilon_\ell}{mc^2} + \theta^2 \gamma^2},$$

where the scattering angle is $\pi - \theta$, and ϵ_ℓ is the energy of a laser photon that collides with an electron of energy γmc^2 . Thus, for a laser operating at $\lambda = 3511 \text{ \AA}$ so that $\epsilon_\ell = 3.5 \text{ eV}$, and with the X-ray Ring running at 2.5 GeV , the maximum backscattered photon energy is $3 \times 10^8 \text{ eV}$ or 300 MeV . The laboratory cross section for this process is very highly peaked about $\theta=0$, with the result that this γ -ray beam is inherently well confined. The spectrum of these backscattered γ -rays is shown in Fig. 5.1 (bottom). There is a one-to-one relation between the γ -ray energy and the angle θ (the scale for the latter is shown at the top of Fig. 5.1), and essentially all of this beam is contained within a 1-mrad cone centered about the electron beam direction in the straight section. Because of this relation between energy and angle, a low-energy part of the spectrum of Fig. 5.1 may be cut out from the γ -ray beam by collimation. Whatever is transmitted by such a collimator is then transported in vacuum to a target where a variety of nuclear and/or

elementary particle experiments can take place. A variety of laser lines can be utilized at LEGS. For most of the running time an argon-ion laser will be used. The maximum γ -ray energies attainable are listed in Table 5.1. In each case, the shape of the spectrum will be identical to Fig. 5.1, with only a change in the horizontal scale.

The energy of a particular γ -ray within the LEGS beam is determined by detecting the scattered electron that gave up energy to boost up the photon energy. This provides an electronic tag for each γ -ray. To accomplish this, a "tagging spectrometer" has been installed in the X-ray Ring tunnel in the region of the short straight between the ring dipoles X1BM1 and X1BM2. The layout of this spectrometer is shown in Fig. 5.2. The first element of this spectrometer is the ring dipole X1BM1, which we also refer to as D1. Three new magnetic elements, referred to as D2, D3, and D4 have been added. (Provision has been made for a quadrupole Q which may be installed at a future date.) This system is capable of transporting scattered electrons to a shielded focal plane area with the ring operating at any energy up to and including 3.0 GeV.

The various components and areas associated with LEGS are shown in Fig. 5.3. There are several distinct interlocked zones, namely the tagging cave, the laser hutch, the target room contained in a new addition to Bldg. 725, the vacuum pipe used to transport the γ -ray beam from the laser hutch into the target room, and a mezzanine (not shown) for air conditioning units located above the computer room in the new addition. The criteria for entry into each of these is described in the subsequent sections.

Finally, LEGS also uses a port, designated X5B, that looks at x-rays from synchrotron radiation emitted at a point $1\text{-}1/4^\circ$ into the bend of dipole X1BM1. This is used as a diagnostic to monitor the position of the electron beam in the ring. The x-rays from this port are entirely contained within a pipe, housing ionization chambers, which terminates in a lead stop, and all of this is entirely contained within the laser hutch.

5.2 Description of LEGS Operation

All components critical to LEGS operation, the laser, the tagging spectrometer, etc., are remotely computer adjusted and monitored from a central control room in the new building addition (the smaller of the two

rooms marked as 'Computer/Data Acquisition' in Fig. 5.3). The detailed plan and elevation views of the 0° and $1\text{-}1/4^\circ$ beamlines, from the dipole magnet X1BM1 to the entrance of the target room, are shown in Fig. 5.4 and 5.5, respectively. The scale at the bottom of each gives the distance from the magnetic entrance point of X1BM1. The concrete-shielded tunnel of the ring contains the standard photon mask, 150mm VAT high vacuum valve, and bremsstrahlung shutter, which are all common to both the principle 0° line and the $1\text{-}1/4^\circ$ -X5B monitoring line. The vacuum pipes for these two lines split in the shielded tail piece (BS-1) immediately after the safety shutter. The laser hutch butts up against the outer concrete shield wall. The high vacuum system within the hutch is isolated from the front end components by 100mm and 60mm VAT valves on the 0° and $1\text{-}1/4^\circ$ lines, respectively. The $1\text{-}1/4^\circ$ line terminates in a $1/4$ " thick water-cooled Al window just after the 60mm VAT valve. This line is normally pumped out through the front-end, although a 20 l/s ion pump and a roughing valve have been located between the window and the VAT valve to allow for future service needs. The high vacuum system of the 0° line within the laser hutch has three different pumping systems. A CTI-8 cryopump is used to bring the system down to pressures in the 10^{-8} torr range. This is then isolated by a right-angled VAT valve. A 220 l/s ion pump, equipped with a Ti sublimator, and a cryoshroud (a 30 mm long copper tube cooled by a CTI-cryodyne to about 20°K) are then used to maintain pressures below 2×10^{-9} torr. The cryoshroud is used to reduce hydrocarbon contamination of the laser window, and is only cooled after the system has reached the 10^{-8} torr range. There is nominally no synchrotron radiation at 0° . However, small amounts of synchrotron radiation can enter the 0° line, these being due to the fringe fields of X1BM1 and X8BM2, and possible misalignments in the electron beam. A double quartz optical window, immediately after the cryoshroud, isolates the ultra-high vacuum of the ring. The inner of these two windows is 1.5 mm thick quartz and is used as an x-ray filter to absorb most of the synchrotron power. The outer window is 3 mm quartz and is used to isolate the ring vacuum system.

Upon leaving this double window the γ -ray beam traverses a 3 mm thick quartz lens, about 4 m of air, and a 4 mm thick Be mirror mounted on the laser optical bench. After the Be mirror are a set of vertical and horizontal nickel slits which can be used to collimate the γ -ray beam. Immediately following the slits, and separated by a 0.5 mm thick mylar window, 5.7 cm high x 10.8 cm across, starts a rough vacuum line ($\approx 10^{-1}$

torr). Following this window, the beam passes through the poles of a sweeping magnet that removes e^+e^- pairs from γ -rays that have converted in the windows, the various optical elements, or along the edges of the slits. These pairs are stopped in lead, and all of this is located at the end of the laser hutch so that only a clean γ -ray beam, well confined within a vacuum pipe, leaves the hutch area.

The 99.9% envelope of the γ -ray beam at the slits is 40mm horizontally x 14mm vertically. Immediately following the moveable slit jaws is a large nickel mask with a hole 80mm x 28mm, and the rough vacuum line following the slits is aligned along the axis of this hole. This allows for motions of the γ -ray beam of ± 20 mm horizontally x ± 6 mm vertically. The momentum vector of the γ -rays is always parallel to that of the electrons within the straight section. To allow for larger horizontal motions in the backscattered γ -rays due to displacement and/or angle changes in the electron orbit, the Ni mask and the rough vacuum γ -ray transport line can be shifted as a unit 20mm to the right or 20mm to the left. To verify consistent alignment, each low-vacuum beamline support outside the target room is equipped with a metal template of three holes (labeled A,B,C) and is padlocked, with the locks going through holes of the same designating letter. The vertical position of each of the low-vacuum beamline supports outside is surveyed and padlocked into position. The slit mask will be aligned to the corresponding position of the γ -ray transport line elements. As discussed below in section 5.3.1.2.3, the mask does not need a similar pad lock since its position does not effect the outer radiation limits outside the hutch.

At the outer access corridor of the NSLS, two large (7" I.D.) valves isolate the section of pipe that crosses this corridor. This pipe must be removable to allow for moving large pieces of equipment around the building. The pipe across the corridor is interlocked with KIRK keys to the safety system. Following this, the vacuum line transports the γ -rays into the target room of the new building addition. If either the vacuum in the γ -ray transport line fails, or one of the 7" valves closes, or the sweeping magnet de-energizes, the radiation levels near the X5 line between the laser hutch and the target room do not become life threatening. Nevertheless, to avoid prolonged operation with higher than necessary ambient radiation levels, all of these elements are interlocked to the bremsstrahlung safety shutter. Specifically, the magnetic field in the sweeping-magnet gap is sensed

directly; microswitches on the 7" valves sense their positions, and a temperature-compensated thermocouple gauge just inside the wall of the target room monitors the pressure in the γ -ray transport line. Failure of any one of these closes the bremsstrahlung safety shutter.

The entire target room is interlocked and is treated as a standard x-ray hutch. Within this room a variety of experiments will be performed with different apparatus. The γ -ray beam will exit the low-vacuum system within this target room through a .003" mylar window that is typically 5" horizontally x 2" vertically. The point at which this occurs will vary depending upon the measurements being conducted. The upstream valve (the one farthest from the target room) is pneumatically actuated. A control signal from the thermocouple gauge, permanently located just inside the target room on the γ -ray transport line closes the upstream 7" valve upon sensing a pressure rise, in order to minimize the effects of window failure. The γ -ray beam never leaves this room and the shielding in this addition has been designed to allow the beam to hit any material anywhere within the room. Normally, γ -rays that have not interacted with any target material are stopped in nickel located in the concrete shielded dump at the end of the room (see Fig. 5.3).

The LEGS beam may be turned off in one of three ways: by actuating a shutter that blocks the laser light, by closing the bremsstrahlung shutter, or by closing the γ -ray slits completely. Nonetheless, no one is allowed access to the laser hutch, the target room, the beam line between them, or the mezzanine above the computer room, unless the bremsstrahlung shutter is closed.

The tagging cave contains thin detectors which measure the position of the laser backscattered electrons that traverse them. These electrons enter this shielded enclosure through a slot in the concrete through which the vacuum pipe protrudes, leave the vacuum through a 1.5 mm aluminum window, traverse about 1.9 m of air and 3 cm of plastic scintillator, and exit through another slot in the concrete shield wall. They are finally stopped in a nickel dump located inside the concrete-shielded tunnel of the X-ray Ring. The door to this tagging cave is interlocked so that entry is permitted only if (a) the injection shutter is disabled and (b) the tagging magnets are not energized.

The interlock system has been designed and built by the NSLS, and LEGS will always operate with someone present who has been adequately trained in its use.

5.3 Hazards and their controls

5.3.1. Radiation hazards and shielding

All controls for radiation protection have been designed to be consistent with operation of the ring at either 2.5 GeV and 300 mA, 2.8 GeV and 200 mA, and 3.0 GeV and 150 mA.

For conformity with the vast majority of beamlines constructed on the NSLS X-ray floor, LEGS is treated as a high-hazard radiation area. Three major classes of radiation hazard are encountered; synchrotron radiation, γ -rays, and energetic electrons.

The synchrotron radiation hazards are those associated with a standard NSLS bending magnet beamline. The hutch construction (3.1 mm thick steel) and the interlock systems conform to the standards outlined in Section 6 of the Phase I SAR (BNL 51584). Such conformance, together with the commissioning procedures outlined in Section 2.5 of the present document, assure that radiation levels will not exceed 0.5 mRem/hr anywhere outside the hutches (in accordance with DOE Order S800.11 for continuously-occupied areas). Estimates of the synchrotron radiation levels inside the hutch, during normal operation, and during special alignment operations are discussed in section 5.3.1.1 below.

The γ -ray hazard is due to both bremsstrahlung and the LEGS beam itself. The LEGS beam is more highly collimated than the expected bremsstrahlung and is located completely within the bremsstrahlung core. Its energy spectrum extends to an anticipated maximum energy of 380 MeV for 2.5 GeV operation (see Table 5.1), whereas the bremsstrahlung spectrum extends to 2.5 GeV. As a result, it is reasonable to expect that shielding designed to reduce the bremsstrahlung hazard to acceptable levels will also be effective against the LEGS beam at the same time. Appendix IV of the Phase I SAR (BNL 51584) develops the bremsstrahlung shielding requirements: 34 radiation lengths along the bremsstrahlung direction and 4.1 Molière lengths transverse, beyond the extremal rays. In lead, these requirements

translate into 8" and 2", respectively. Shields which meet or exceed these requirements are in place, in the arrangement prescribed in Appendix IV, all along the LEGS beamline where γ -rays may be present (see Fig. 5.9 and Fig. 5.10). In section 5.3.1.2 below, the shielding is described in greater detail, and dose estimates are made for high-occupancy areas for a worst-case target in the worst-case location in the target room. In all such cases, the estimated doses are below 100 mRem/yr (in accordance with DOE Order S800.11 for non-radiation workers). Additional dose estimates are also made for various worst-case multiple-fault situations. In none of these cases is the estimated dose life-threatening.

The electron hazard is confined to the tagging electron cave located in the inner wall of the X-ray Ring tunnel. The cave is interlocked to prevent personnel entry whenever electrons could be present, and is shielded to prevent scattered radiation from leaving the cave. Details, and dose estimates for worst-case fault situations are given in section 5.3.1.3.

5.3.1.1 Synchrotron radiation

A small amount of synchrotron radiation is possible in the 0° line due either to the fringe field of the magnet X8BM2 and the field near the edge of dipole X1BM1. This radiation will strike the 0° quartz windows and would normally be highest in both intensity and energy at the inside edge of the window which is 16 mm in diameter. The spectrum of synchrotron radiation transmitted by the 4.5 mm quartz windows, integrated over the angular acceptance of the windows ($0 \leq \theta \leq 0.9$ mrad), is shown as the dashed curve in Fig. 5.6. This has been calculated using measured fields in an x-ray dipole magnet set to simulate operation at 3.0 GeV. At the 150 mA limit for this energy, the integral of this spectrum gives 4.3×10^8 photons- s^{-1} , which are peaked at 14 KeV. These travel straight across the optical bench and are stopped in the Ni slit assembly (d=14 m in Figs. 5.4, 5.5), which is shielded on all sides. The most localized scattering source before the Ni slits is one of the laser optical components on the bench. For example, 7% of this x-ray flux will scatter from a 2 mm thick quartz lens. At 14 KeV this scattering is roughly isotopic, so that the flux density inside the hutch, near the wall 1.2 m away, would be 1.55×10^2 $s^{-1}cm^{-2}$. At 14 KeV, 90% of the energy would be deposited in 2 cm of flesh (approximated by water) so that this flux density would produce a dose in a person of $5.6 \times$

10^{-5} Rads/hr. This is negligible, and represents the normal steady-state operating conditions when the laser and the electron beam are aligned.

In the course of maximizing the backscattered γ -ray flux, the momentum vector of the laser light is scanned in both displacement and angle. To facilitate this, the quartz windows can be displaced horizontally by ± 27 mm. This process of optimization usually takes a few minutes. However, during this time the windows and the electron beam direction can be quite misaligned. The highest radiation level will be encountered when the window is displaced by the maximum amount to the inside of the ring. If we further assume that the electron beam is displaced by 10 mm to the outside of the ring, then the inside edge of the window is exposed to light emitted at 5 mrad into the bend. The spectra of synchrotron radiation transmitted by the windows for this geometry is shown as the solid curves in Fig. 5.6 for different possible energies of the ring. At 150 mA, the integral of the solid 3.0 GeV curve gives 2.3×10^{13} photons- s^{-1} . A 7% scattering source now produces a flux density of 7.9×10^6 $s^{-1}cm^{-2}$ inside the hutch, and at the wall 1.2 m away. The mean energy of these photons is 20 KeV, and 90% of this energy is absorbed in 5 cm of flesh (approximated by water) so that this flux density would produce a dose in a person of 1.6 Rads/hr. These fluxes are orders of magnitude higher than those of steady-state LEGS operation, but are still far less than those of a standard x-ray beamline and, in any case, only occur for short periods of time. A good deal of this radiation is stopped in the 2" of lead on either side of the optical elements (Fig. 5.4), and the walls of the laser hutch are made from 1/8" steel panels, following the standard NSLS hutch construction. The only openings in the hutch upstream of the Ni slit assembly are the window in the upstream door, which is covered with leaded-glass, air vents near the floor in the side panels, which are shielded by 1/8" steel to prevent direct line of sight from any possible scattering sources, and the air intakes in the roof. The roof is split into two levels, one at 9 feet and one at 13 feet. There is one air intake in the 9 foot section which is shielded on the inside of the hutch with steel to prevent any direct line of sight to the beam line. The 13 foot section has 3 air intakes in it. This region is, at best, very difficult to access, and a warning light together with an accompanying sign is placed on the 9 foot landing to control access to the 13 foot roof when the bremsstrahlung shutter is open.

The 1-1/4°-X5B line is entirely contained in a 1/8" steel-walled metal box, fastened directly to the 1/4" thick aluminum vacuum window, and is followed by a lead stop from which no radiation leaves.

5.3.1.2 Gamma radiation

5.3.1.2.1 Hazard level of the LEGS beam

The hundreds of MeV backscattered γ -rays in the LEGS beam, like the bremsstrahlung from gas in the straight section, are not significantly affected by the optical windows or even the steel hutch walls. The laser hutch serves chiefly as a personnel exclusion zone around the γ radiation and around apertures that may be struck by this high-energy radiation as well as a clean room for the laser components.

The maximum flux in the LEGS beam will be about $3 \times 10^7 \text{ sec}^{-1}$. Behind the laser hutch, this beam has a cross section of approximately 3 cm wide x 1 cm high, and the maximum dose incurred by someone standing in this beam would be accumulated along the path of the beam. Approximating the human body by 30 cm of H_2O , this peak dose is plotted in Fig. 5.7 as a function of γ -ray energy. These, and all subsequent calculations have been carried out using the Monte Carlo Shower code, GEANT3.11 (CERN DD/EE/84-1; rev. 87/1). All of the optical components, the lead/nickel beam line apertures open to their widest extent, and air in the γ -ray beam line have been included in these calculations, and all 3×10^7 photons per second were assumed to have the same energy.

The γ -ray spectra, such as is shown in Fig. 5.1, have only a small variation with energy. In order to save on computer time, in all subsequent GEANT calculations, all photons were assumed to have 150 MeV of energy. When the maximum LEGS energy is 300 MeV, this approximation is about 10% too pessimistic. If the maximum γ -ray energy is increased to 500 MeV, then this approximation becomes about 20% too optimistic. With this approximation, the dose profile in water is shown in Fig. 5.8. This peaks at 900 Rads/hr. near the beam center, but falls by nearly four orders of magnitude in 15 cm - an average human body radius. Since only a small portion of the body can be exposed to a high radiation level at any one instant, the maximum "reduced dose rate" for someone standing in the LEGS beam becomes $900/50 =$

18 Rads/hr, following the prescription given in the Laboratory Safety Manual, Section 3.4.0.

So far these calculations have included only electromagnetic radiation. The neutron contribution can be estimated as follows. From the GEANT calculation, the peak dose of 900 Rads/hr. accumulated along the beam is the result of an energy deposition rate of 49 MeV per photon. Swanson, Health Phys. 37(1979)347, gives the approximate neutron yield as 3.4×10^{-4} neutrons per MeV deposited. These are produced towards the end of the shower and come chiefly from the Nuclear Giant Dipole Resonances, and average 7 MeV in energy. The 3×10^7 incident photons per second would then produce about 5×10^5 neutrons- s^{-1} , which are emitted roughly isotropically. These neutrons emerge through the beam envelope which, through 30 cm of water, has a surface area of 195 cm^2 . The peak neutron flux density is thus $2.54 \times 10^3 n-cm^{-2}-s^{-1}$. Including the quality factor given for 7 MeV neutrons in ANNEX A of Section 3.1.0 of the Laboratory Safety Manual, this corresponds to 0.4 rem/hr.

5.3.1.2.2 LEGS gamma-ray and bremsstrahlung shielding

The three exclusion zones, the laser hutch, the target room, and the vacuum pipe between them, are all interlocked to prevent direct exposure to the γ -ray beam. Pb shielding is incorporated into these areas to prevent any radiation up to 3.0 GeV from penetrating these zones. The bremsstrahlung shielding is a minimum of 35 radiation lengths of lead. The plan and elevation views of the bremsstrahlung containment apertures are shown in Fig. 5.9 and 5.10, respectively. The bremsstrahlung limits are drawn as radiating from the entrance point of the X1BM1 dipole magnet. The outermost rays in Fig. 5.9 (projecting downward in the drawing) radiate from the innermost possible source point allowing for a maximum displacement of 100 mm towards the center of the ring. The innermost rays (projecting upward in the drawing) radiate from the outermost source point allowing for a maximum outward displacement of 30 mm. The extreme rays in Fig. 5.10 correspond to maximum vertical excursions of ± 10 mm. The outer dimensions of the various bremsstrahlung shields (labeled BS-1 to BS-11 in Fig. 5.9 and 5.10, as well as in Fig. 5.4 and 5.5) are listed in Table 5.2.

The shielding at those areas that could regularly be struck by a significant portion of the LEGS γ -ray beam, namely the collimating slits

inside the laser hutch and the dump at the back of the target room, consists of 16 radiation lengths of nickel, followed by 20 radiation lengths of lead behind the slits, and by concrete and earth behind the beam dump. Nickel has been used as the primary absorber in the γ -ray facilities at the University of Mainz and at the ALS in SACLAY. Nickel has an anomalously low (γ, n) cross section and its use has reduced neutron production by a factor of about four. The slit assembly consists of a mask which limits the maximum bremsstrahlung aperture to 80 mm horizontally and 28 mm vertically. Two sets of remotely operated jaws, one vertical and one horizontal, serve to reduce the γ -ray aperture further down to full closure. The position of the slit mask is adjustable ± 20 mm horizontally and ± 10 mm vertically; the position of the slit mask, however, does not effect the outer bremsstrahlung limits extending outside of the hutch area. The entire beam line is made to be positioned in three discrete horizontal locations, center and ± 20 mm, each position being secured by padlocked bolts. The optical elements in the path of the γ -ray beam have 2" of lead on either side of them. The Ni slits, which may be intercepting a substantial fraction of the beam, are flanked by walls of both 2" lead and 4" borated polyethylene.

5.3.1.2.3 Sweeping magnet for secondary charged particles

The total amount of material before the start of the low vacuum system amounts to 11% of a radiation length. Electron-positron pairs that can be produced by the γ -rays, including bremsstrahlung, while traversing this material are deflected out of the γ -ray beam in a magnetic field of 1.31 Tesla produced by a "sweeping" magnet. The γ -rays are transported from the entrance of this magnet to the target in an evacuated pipe, so that essentially no pair production can occur after the sweeping magnet. At the downstream end of the sweeping magnet, the beam pipe is surrounded with lead and borated polyethylene to stop the shower from the deflected pairs. A computer code for tracing charged particles was used to determine the trajectories of electrons from pair production. Fig. 5.11 shows the layout of components in the downstream section of the laser hutch with a set of computed electron trajectories. Each trajectory shown in this figure was computed for the worst case, starting 40 mm from the nominal beam center line, at the limit of the 80 mm x 28 mm beam limiting slit mask, on the side opposite the deflection. The initial angle for each trajectory was taken as the sum of 2 mrad and mc^2/E , the mean half angle of the pair again in the direction opposite the deflection. These conditions cause the computed

trajectories to exit the laser hutch as close as is possible to the beam centerline and are therefore the conditions that represent the worst case for shielding. A similar set of worst-case positron trajectories (not shown) enter the magnet on the opposite side of the beam-limiting slit aperture and are bent in towards the steel of the magnet (down in Fig. 5.11). All rays traverse a minimum of 35 radiation lengths of lead, which is surrounded by a minimum of 4" of borated polyethylene.

5.3.1.2.4 Radiation level outside interlocked areas

The γ -ray transport line between the laser hutch and the target room is pad-locked and/or Kirk-locked in place. With rough vacuum (10^{-1} torr) in this line, the two 7" (I.D.) gate valves flanking the outer equipment-access-corridor open (last sheet of Fig. 5.4), and the sweeping magnet energized, the radiation levels due to LEGS behind the laser hutch and outside the vacuum pipe will be completely negligible. The vacuum in this line is sensed by a temperature-compensated thermocouple gauge, the positions of the two 7" gate valves are sensed with microswitches. Both the field in the sweeping magnet gap, and the current in the coils are sensed, and all of these are interlocked to the "experimental-interlock" circuit which closes the bremsstrahlung shutter if any of these detect an unsafe condition. Should this interlock fail, the radiation levels in the vicinity of the γ -ray transport line are shown in Fig. 5.12. This has been calculated with GEANT for someone, approximated by a 30 cm thickness of H_2O , standing near the second 7" gate valve ($d = 26000$ in Fig. 5.4) with air in the beam line, the sweeping magnet off, the γ -ray beam in its worst-case limit as close as possible to the pipe wall, and with the nickel beam-defining slits open to provide the maximum aperture. The solid, and dashed, curves give the dose with the valve open, and closed, respectively. The dose is at most 62 mRads/hr. and drops very rapidly with distance from the pipe. Decreasing the beam-defining aperture by reducing the Ni slit opening reduces these levels even further.

5.3.1.2.5 Target room shielding

An enlarged view of the target room is shown in Fig. 5.13. There are two nominal target locations, at $d = 30.5$ m and $d = 37.2$ m from the X1BM1 magnetic entrance point. The interlocked portion of the beam pipe terminates at the $d = 29.1$ m point (Fig. 5.13) just inside the door. Within

this interlocked target room, the LEGS beam may strike one or more targets, one of which might be an appreciable fraction of a radiation length in thickness. When the target is thin enough to transmit most of the resulting energy, the radiation is highly forward peaked and is mostly contained in a few degree cone about the beam direction. Essentially all of this will enter the shielded dump cave which is below grade level. Nonetheless, the radiation shielding for this room has been designed assuming the worst case, namely that the entire beam is stopped in a thick target located somewhere in the room before the dump.

The highest possible hazard due to ionizing radiation would occur if the maximum intensity LEGS beam struck an appreciable thickness of material at the termination of the interlocked beam pipe just inside the room ($d = 29.1$ m). The minimum distance from here to a point immediately outside the target room equipment door (along the stairway that goes under the beam pipe) is 0.8 m. The inside of the door and the adjacent wall have been lined with 1/2" lead sheet (cross-hatched strip in Fig. 5.13) extending from the floor up to a height of 7 feet. The width of this lead shield has been adjusted so that the distance from the $d = 29.1$ m point on the beam line to the ends of the lead is 2.0 m. The dose to someone standing either 0.8 m or 2.0 m from the $d = 29.1$ m point, due to 3×10^7 photons per sec striking one radiation-length of lead at the end of the pipe, has been calculated with GEANT and the results are summarized in Table 5.3. These radiation levels are quite small, especially for a walkway area that is not normally occupied. The computer room will have a much higher occupancy level. The minimum distance from here to a source located anywhere along the beam line is 2.0 m. Assuming an occupancy of 2000 hours/year, the level given in Table 5.3 implies 0.06 Rads/year, which is further reduced by the one foot thick wall of normal-density concrete block (density of 2.24 g/cm^3 , [140 lb/ft^3]).

A greater potential radiation component to the high occupancy computer area is the neutrons that are created in the target. Assuming as a worst case 3×10^7 photons per second, which deposit all 150 MeV of their energy, then 3.4×10^{-4} n/MeV (Swanson, Health Phys. 37 (1979) 347) or 1.5×10^6 n/s will be created. These come mainly from the nuclear giant dipole resonances, average 7 MeV in energy, and are emitted roughly isotropically. The closest point to the beam line in the inside of the computer room is 2.0 m away. Here the maximum neutron flux density is $3.0 \text{ n-s}^{-1}\text{-cm}^{-2}$. Including

the quality factor given for 7 MeV neutrons in Annex A of Section 3.1.0 in the Laboratory Safety Manual, this corresponds to a dose of 0.45×10^{-3} Rem/hr. Assuming an occupancy of 2000 hours/year, the accumulated dose would then be 0.89 Rem/year. The computer room has been lined with a 1 ft. thick layer of normal-density concrete (Fig. 5.13). This reduces the maximum accumulated dose by about a factor of 12, to 0.07 Rem/year.

High energy neutrons (100 MeV) are emitted from the $\Delta(1232)$ baryon resonance, which peaks at 300 MeV in photon energy. These are about a factor of 100 less intense than the giant resonance neutrons that come from the end of electromagnetic showers. They have a strongly forward-peaked angular distribution and are not a problem to personnel in the computer/data acquisition rooms. To contain them, and the small numbers of large-angle photons and electrons that might get out of the target, the back of the target room is lined with a 1 ft. thick wall of normal-density concrete to a height of 10 ft. above the beam line, or 7 ft. above grade outside the dump. In width, this wall subtends a half-angle of $22\text{-}1/2^\circ$ at the $d = 30.5$ m point (the center of the small circle in Fig. 5.13).

5.3.1.2.6 Radiation interlocks

The radiation interlock circuit for LEGS uses the standard captured key system, designed around KIRK locks, that is used throughout the NSLS. There are three subsystems, each of which must be separately satisfied in order to operate the branched safety shutter. These are (1) the laser hutch, (2) the removable vacuum pipe that crosses the outer access corridor of the building, and (3) the target room and the equipment mezzanine above the computer rooms in the new addition. Standard transfer boxes are used to provide keys for the various doors to the target room and locked components of the beam line. The locations of these interlocked doors and components are shown as the heavy cross-hatched regions in Fig. 5.14. The search procedure for the target room requires leaving via the inner computer room door. The search procedure for the laser hutch requires leaving via the door closest to the ring. In the target room a siren and a red rotating beacon are activated when the search procedure is initiated. In the laser hutch, the standard red warning lamp is used. The target room, the mezzanine, and the laser hutch are each equipped with several of the standard red crash buttons that can close the safety shutter and dump the ring in case of emergency.

The steel box that confines the x-rays from the X5B monitoring line is entirely contained within the Laser hutch and is equipped with two KIRK locks that must be satisfied before the X5B safety shutter can be opened. This is electronically independent of any of the other interlock systems.

5.3.1.3 Tagging electron cave

5.3.1.3.1 Shielding

The tagging cave is built as a protrusion into the X-ray Ring tunnel with an access door from the center of the building in the region of the RF power supplies (light cross-hatch region in Fig. 5.14). The cave has inner dimensions of 22" x 66" and is constructed of normal-density concrete, with an 18" thick wall through which the tagging line vacuum chamber passes, and 9" thick side and end walls. All the booth walls are lined on the inside with 0.275" borated flex panel (Reactor Exp., Inc.) and 1/2" thick lead sheet, including the sliding access door, whose basic structure is a 3/4" plywood. The roof is made from 1/2" steel plate and is covered by 1/4" of lead and 4" of borated polyethylene. The tagging electrons pass through this booth, and re-enter the ring tunnel through a 3-1/2"x19" slot in the end wall. Because of the finite acceptance of the spectrometer, only half of the scattered electrons reach this cave. These are spread out in a fan that is 0.3 cm high and at least 30 cm wide. In someone, approximated by 30 cm of H₂O, standing in this fan, each electron would deposit about 60 MeV of energy. This would correspond to a dose of 192 Rads/hr. However, since the cross section of this fan of electrons is only 9 cm² then, following section 3.4.0 of the Laboratory Safety Manual, this corresponds to an effective "reduced dose rate" of 3.8 Rads/hr. Normally, the tagging electrons pass through only thin scintillators (1 cm) and, because of their high energy, undergo very little scattering and cleanly exit the cave. Once inside the ring tunnel, the electrons pass through 12" of borated polyethylene and are stopped in 20 radiation lengths of nickel.

5.3.1.3.2 Interlocks

Access to the tagging focal plane cave is prevented when 1) the tagging magnets are on or when 2) electrons are being injected into the X-ray Ring. With the tagging magnets off and injection disabled, access to the cave is permitted with beam stored in the ring, since there is no direct

line of sight between the cave and the region of the ring dipole magnets. The electrical interlock system provides two levels of protection. At the first level, in order to obtain the key to the focal plane cave door, the user must remove it from an electronic lock in the LEGS control area. This turns off the tagging magnet power supplies and closes the injection shutter. (In order to allow the magnets to be turned on, or to permit injection, the key must be replaced in the electronic lock in the LEGS control area.) As a second level of protection, when the tagging cave door is open, an interlock switch on the door turns off the tagging magnet power supplies and disables injection.

5.3.2. Electrical hazards

The electrical power needed to operate the laser and the tagging and sweeping magnets is distributed to the five main power supplies at 480 VAC, 3 phase, with a grounded wye system. Smaller power supplies and control equipment are operated from a 115/208 volt system. All of these supplies are presently located behind the laser hatch. The installation of this distribution equipment is according to standard industrial practice for equipment of this type and conforms to applicable ANSI National Safety Codes. All power supply cabinets are locked and doors and panels are interlocked so that opening a cabinet trips the main circuit breaker within the cabinet. The tagging and sweeping supplies deliver moderately high currents (less than 2000 Amps) at low voltage (less than 50 volts) to magnets located inside the X-ray Ring and inside the X-5 laser hutch. All terminals on the magnets are covered with protective lucite shields so that no conductors are exposed, and an amber rotating beacon attached to each magnet is activated whenever the magnet is energized. The three largest supplies are equipped with ground fault circuit interrupters. The laser power supply is located with the laser inside the hutch and is similarly interlocked.

5.3.3. Laser light hazards

5.3.3.1 UV laser

The LEGS laser hutch presently hosts a class IV cw-argon ion laser 30 watts max. visible or 6 watts max. UV. This laser can be operated either from a computer located outside the hutch or directly from inside the hutch.

The safety system for light hazard protection consists of a graphite shutter placed right after the box housing the laser cavity, that is interlocked to a keyed security system. This system is completely distinct from the radiation safety system.

The laser security system requires a search of the laser hutch, depression of one button at a check station located at the end of the hutch and within only a short time interval, closing all hutch doors and depression of a second button located near the normal access door (the one closest to the ring in Fig. 5.3). There are two possible choices for the second button, one just inside the door for tuning up the laser with operators in the hutch with the doors closed, and one just outside the door for normal operation. Following this sequence, the laser security key must be placed either in an electronic box inside the hutch, or in an identical box near the LEGS control room. The key must be turned in one of these boxes in order to enable the laser shutter, and once enabled the key is captured.

Microswitches, distinct from those of the radiation safety system, sense the position of the hutch doors. If a door is opened while the laser shutter is open, the laser power supply is turned off. For certain maintenance procedures, the laser has to be operated without its protective cover over the cavity. The position of this cover is also sensed by switches and normally, if the cover is not in place, opening one door turns off the power supply regardless of the laser shutter status. During maintenance, the cover interlock can be bypassed. The light from the LEGS argon-ion laser which leaves the hutch is completely contained inside the vacuum pipe and traverses the straight section of the ring and reaches the 180° port inside the tunnel. There a power meter is directly coupled to the pipe to ensure no light leak. Occasionally, during tune-up operations, this power meter has to be removed. In these circumstances, a trained LEGS staff member is in constant attendance at the location of the open beam with a radio to communicate with the person operating the laser.

5.3.3.2 CO₂ laser

In the center of the injection straight section, a class IV CO₂ laser is installed. This is used to calibrate the electron beam energy. Its maximum power is 7 watts in the infrared region (nothing visible). This

laser is operated from outside the tunnel and is fully enclosed in a plastic cover that is opaque to infrared. The laser has an internal shutter that under normal conditions is interlocked with the cover. If the laser has to be operated without the plastic cover, the access to the area is restricted to only authorized persons of the LEGS group.

5.3.4 Cryogenic hazards

Various liquid targets, such as liquid hydrogen/deuterium, will be used in the target room. The operation of each of these requires a separate review by the BNL Cryogenic Safety Committee (CSC) which is entirely responsible for determining their safe mode of operation. Each target will have a set of status indicators both in the LEGS control room and in the NSLS control room. These indicators are target specific and are determined by the CSC.

At a meeting on March 14, 1988, the CSC made the following recommendations regarding the operation of the LEGS target:

- a. Whichever group is selected to operate the target/reservoir systems should have those duties as their primary responsibilities, not ancillary responsibilities to other duties.
- b. Experimenter control of the target system is strongly discouraged.
- c. Any person trained as a target operator should receive formal, well-documented training and certification.

In response, the NSLS has developed the following program for LEGS target operation:

There will be a properly-trained Operations Coordinator on duty whenever the LEGS target is in operation, in addition to the regularly-scheduled Operations Coordinator. The coordinator assigned to target watch will have as first priority the periodic monitoring and control of the target and the response to any emergency conditions at the target. As a secondary assignment, the person on target watch will share the duties of the shift coordinator.

5.3.5 Egress

Egress requirements conform to Life Safety Code (NFPA 101-85) and Occupational Health and Safety Standards (OSHA-1910) for egress.

Special provisions for egress were made at the outer 6-foot equipment-access corridor of the building where the γ -ray beam line crosses into the LEGS building addition. The normal walking path through this area is provided by a 42" wide underpass accessed by two sets of stairs, adjacent to the 6 ft. corridor, that drops down to a level below the beam pipe and then rises back up again. A new emergency exit was incorporated into the LEGS building addition so that now, with the exit near X3, there is an emergency building exit close by on both sides of this pipe. The pipe across the corridor is removable to allow passage of pieces of equipment that for some reason cannot go around the building in the other direction. This involves breaking the interlocked security and will be scheduled as the need arises.

5.3.6. Accident Assessment

The assessment of a bremsstrahlung accident caused by a loss of vacuum in the ring is the same for LEGS as it is for any other beam line and is covered in the Phase I SAR (BNL 51584). For the LEGS beam itself, the radiation levels of the direct γ -ray beam or of the tagging electron beam, although high, are very localized so that the effective "reduced dose rate" (Laboratory Safety Manual, Section 3.4.0) is not immediately life-threatening. For an accident to occur, the following systems or procedures must fail:

- 1) The trained personnel would have to fail to carry out the prescribed inspection procedures.
- 2) The interlocks on the entry points to the laser hutch, beam line, mezzanine, and/or target room must fail to close the bremsstrahlung safety shutter and fail to dump the ring, or the interlocks on the door to the tagging cave must fail to turn off the tagging magnets and fail to close the injection shutter and fail to dump the ring.

The backup to the safety interlock system consists of the emergency off buttons which are located at several points around the inside walls of the

laser hatch, the target room, and the mezzanine area. When pressed, any one will revoke the interlock-enable status and dump the ring.

5.4 Attachments

5.4.1. List of Tables

- Table 5.1: Maximum γ -ray energies attainable at LEGS
- Table 5.2: Outer dimensions of lead bremsstrahlung shields
- Table 5.3: Dose in 30 cm of H_2O , from 3×10^7 photons/s striking 1 radiation length of lead.

5.4.2. List of Figures

- Figure 5.1: Kinematics of backward Compton scattering, and a typical γ -ray spectrum.
- Figure 5.2: Layout of the LEGS tagging spectrometer.
- Figure 5.3: Schematic overview of the various components comprising LEGS.
- Figure 5.4: Detailed plan view of the beam line from dipole X1BM1 to the target room in the new building addition (3 sheets).
- Figure 5.5: Detailed elevation view of the beam line from dipole X1BM1 to the target room in the new building addition (3 sheets).
- Figure 5.6: Spectrum of synchrotron radiation transmitted through 0° windows.
- Figure 5.7: Peak dose accumulated by someone standing in the LEGS beam as a function of γ -ray energy.
- Figure 5.8: Dose profile in water due to the LEGS beam.
- Figure 5.9: Detailed plan view of the bremsstrahlung containment apertures.
- Figure 5.10: Detailed elevation view of the bremsstrahlung containment apertures.
- Figure 5.11: Electron trajectories in the sweeping magnet.
- Figure 5.12: Dose profile in someone, approximated by 30 cm of H_2O , standing next to the γ -ray beam line, behind the laser hatch, in the event of an interlock failure.
- Figure 5.13: Shielding for radiation confinement in the target room.
- Figure 5.14: Points of access to interlocked regions, shown by the cross-hatched boxes.

TABLE 5.1 Maximum LEGS gamma-ray energies

LASER	λ (Å)	$E_e = 2.5$ GeV	$E_e = 2.8$ GeV	$E_e = 3.0$ GeV
Ar-Ion	5145	210 MeV	260 MeV	300 MeV
Ar-Ion	3511	300 MeV	370 MeV	420 MeV
Nd-YAG	2660	380 MeV	465 MeV	530 MeV

TABLE 5.2

OUTER DIMENSIONS OF LEAD BREMSSTRAHLUNG SHIELDS

DESIGNATION	WIDTH(in)	HEIGHT(in)
BS-1	32.0	16.0
BS-2	4.0	12.0
BS-3(front)	9.0	8.0
(rear)	10.0	8.0
BS-4	19.0	10.0
BS-5	11.0	8.5
BS-6	12.0	10.0
BS-7	16.0	16.0
BS-8	16.0	16.0
BS-9	8.0	8.0
BS-10	6.8	6.0
BS-11	8.0	8.0

Table 5.3: Dose in 30 cm of H₂O, from 3×10^7 photons/s striking
1 radiation length of Lead

Distance from source	Accumulated Dose (Rads/hr)	
	Base level	Level outside 1/2" Lead Shield
0.8 m	0.15×10^{-3}	0.003×10^{-3}
2.0 m	0.03×10^{-3}	

Fig. 5.1

$$E = \frac{4\gamma^2 \epsilon_L}{1 + \frac{4\gamma \epsilon_L}{mc^2} + \theta^2 \gamma^2}$$

Fig. 5.2

06/68

cb/16

Fig. 5.4 continued

95/96

Fig. 5.5 continued

Fig. 5.5 continued

Fig. 5.6

**Spectrum of synchrotron radiation
transmitted through 4.5 mm of quartz
into specified angular range**

Fig. 5.7

Peak dose (accumulated within a beam diameter of 2 cm) in a human body, approximated by 30 cm of H_2O , while standing in a LEGS beam of 3×10^7 γ 's per second, in front of the second 7" valve ($d = 26$ m), with the sweep magnet off and air in the beam line

Fig. 5.8

Fig. 5.10

LEGS - X5 SHIELDING LAYOUT ELEVATION

Accumulated Dose in a human body, approximated by 30 cm of H_2O , while standing next to the second 7" valve ($d=26m$) with 3×10^7 γ 's per second at 150 MeV in the beam pipe, with the sweep magnet off and air in the pipe

Fig. 5.12

Fig. 5.14

SAFETY INTERLOCKED AREAS

6. REFERENCES

1. Weilandics, C., N. Rohrig and N.F. Gmur. 1988. Ozone Production Due to Synchrotron Radiation. Nucl. Instru. and Meth. in Physics Research A266: 691-698.
2. Gmur, N.F. 1988. Analysis of Surface Contamination on Beryllium and Aluminum Windows. Nucl. Instru. and Meth. in Physics Research A266: 362-374.
3. Chapman, D. January 1988. PHOTON: A User's Manual. National synchrotron Light Source, Brookhaven National Laboratory, Upton, NY. BNL Informal Report 40822. 66 pp.
4. Rogers, D.W.O. 1984. Fluence to Dose Equivalent Conversion Factors Calculated with EGS3 for Electrons from 100 keV to 20 GeV and Photons from 11 keV to 20 GeV. Health Physics 46 (4): 891-914.

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: February 28, 1989
TO: NSLS Staff and Users
FROM: K. Batchelor *K.B.*
SUBJECT: Source Size for Maximum Credible Accident in the Storage Rings

Peter Stefan has carried out an extensive study of the source for the "Maximum Credible Radiation Accident" for the 0°, 2.5° and 10° beam ports in the storage rings and as a result, the NSLS Safety Committee has adopted the following standards:

For 0° Beam Ports

The start of the dipole bend should be taken as the source point and the source extent should be ± 21 mm vertically and ± 40 mm horizontally.

For 2.5° and 10° Beam Ports

The tangent point for the port centerline on the "standard orbit" should be taken as the source point and the source extent should be ± 21 mm vertically and 100 mm inboard, 40 mm outboard horizontally.

The NSLS Safety Committee requires that all new beam line shielding be designed to meet these standards and further recommends that existing beam line installations be reviewed to determine whether they meet this requirement. If they do not conform to the new guidelines they should be upgraded.

jt

BROOKHAVEN NATIONAL LABORATORY
M E M O R A N D U M

DATE: April 14, 1989
TO: Distribution
FROM: J. Levesque *JL*
SUBJECT: Magnet Alloys - Bldg. 725

At the request of Peter Stefan, I have reviewed the MSDS (relative to fire protection) on two alloys proposed for magnets (attached).

Neodymium:Boron:Iron and Samarium:Cobalt will be purchased in block form and used in magnets on the VUV and X-Ray rings. The metals will not be used in foils or powder form.

According to the MSDS, these materials will not pose any significant fire hazards. The precautions for fire control are typical to any metal. This material will not be in powder form and fire control is not a concern.

A minor note is the characteristic "sparking" nature of the metal. Precaution should be taken to keep easily ignited materials (papers, combustible gases, etc.) remote when moving the blocks.

JL/sc
Attachment
Distribution
K. Batchelor
P. Stefan ✓
F. Strier
C. Weilandics
f: 1.2
mag_allo.725

A THERMAL ABSORBER FOR HIGH POWER DENSITY PHOTON BEAMS

S. ULC and S. SHARMA

Brookhaven National Laboratory, Upton, New York 11973, USA

The high power density of multipole wiggler radiation from the X-ray ring at the National Synchrotron Light Source at Brookhaven National Laboratory precludes the use of normal incidence water cooled masks and shutters due to high metal temperatures and resulting high stresses and/or deflections and the possibility of cooling water boiling. One way the power density can be reduced is by positioning the absorber surface at a small angle to the beam, a technique first developed by Lawrence Berkeley Laboratory. Finite element analyses results for temperatures, displacements and stresses are presented in this paper for a thermal absorber designed for ultrahigh vacuum operation.

1. Introduction

The basic absorber is a continuous length of hollow core OF copper conductor which has been formed and machined into the required shape and positioned so as to intercept the photon beam at a small angle (see fig. 1). Water connections are made outside the vacuum containment. The advantage of this approach is that fabrication is relatively simple, there are no water-vacuum joints and only two permanent atmosphere to vacuum seals (brazed joints) are required.

Fig. 1. Conceptual design: 6° horizontal absorber.

A two-dimensional finite element analysis is first carried out to obtain the temperature distribution across the absorber cross-section. The resulting thermal deflections and stresses are then obtained by two coupled structural analyses utilizing plane-strain formulation and beam finite elements. Numerical results for maximum deflections and stresses are compared to their corresponding design values.

2. Thermal analysis

The normal incidence peak power density from the X-ray superconducting wiggler at 10 m from the source is 3880 W/cm² with a nearly Gaussian distribution in the vertical plane [1]. Positioning the absorbing surface at 6° in the horizontal plane to the photon beam (fig. 1) reduces the peak power density to 406 W/cm² (3880 W/cm² × sin 6°). The absorber cross-section itself is 5/8" × 1" with a 3/8" diameter water channel through the center. A velocity of 20 ft/s was assumed in the water channel resulting in a 7 gal/min flow and a pressure drop of 3 psi per foot of absorber length. At a water inlet temperature of 25°C, a value of 2.1 W/(°C cm²) for the film coefficient for turbulent flow was determined by means of the expression [2]

$$h_f = \frac{V^{0.8}}{d_h^{0.2}} (0.118 + 0.0016T_b) \frac{\text{W}}{^\circ\text{C cm}^2}, \quad (1)$$

where V is the water velocity (ft/s), d_h is the water channel diameter (in.), and T_b is the bulk water temperature (°C).

Using the absorber geometry, power input and cooling parameters, a 2-dimensional finite element solution was obtained for the temperature distribution within the absorber cross-section. Approximately 500 temperatures were determined yielding important maximum values such as copper temperature, water cooling chan-

Fig. 2. Temperature distribution: 6° horizontal absorber. (a) Zero beam shift. (b) Maximum beam shift.

nel wall temperature (to determine the possibility of boiling) and temperature drop across the film.

Fig. 2a shows the temperature distributions throughout the absorber cross-section when the photon beam is directly over the cooling channel, and fig. 2b shows them when the beam is near the edge of the absorber corresponding to a maximum shift of the beam centerline. These temperatures are based on a water inlet temperature of 25°C. There is a bulk water temperature rise in the absorber of

$$\Delta T_{\text{bulk}} = \frac{3.8 \text{ kW}}{\text{GPM}} = \frac{3.8(7.8)}{7} = 4.2^\circ\text{C}. \quad (2)$$

The maximum cooling channel wall temperature is 66.4°C (62 + 4.2), low enough to preclude any possibility of boiling.

If the absorber is positioned at a small angle in the vertical plane it sees a peak power density at its center decreasing toward its ends as shown in fig. 3a. It sees the beam across its entire width resulting in a maximum power/unit length of 343 W/cm (~ 3 times that of the 6° horizontal absorber) at an angle of 2° to the beam. This is about the smallest angle that can be used due to thermal deflections, fabrication tolerances and alignment requirements. Thermal analysis results (fig. 3b) indicate a maximum copper temperature of 112°C and a maximum water channel temperature of 97°C which is close to the atmospheric boiling temperature of 100°C. Boiling should be avoided in order not to generate steam voids and resulting hot spots. By increasing the exit pressure to 10 psig the saturation (boiling) temperature at 10 psig increases to 116°C. The inlet must necessarily be higher due to the pressure drop in the channel. The bulk water temperature rise is 1.3°C.

Fig. 3. 2° vertical absorber. (a) Geometry and power density distribution. (b) Temperature distribution.

3. Stress analysis

A finite element plane-strain stress analysis technique was used to determine the stress and strain distributions in the cross-sectional plane of the absorber.

This technique assumes that the temperature, stresses and strains do not vary along the absorber's length and its ends are initially fixed (see fig. 4). The absorber should not be fixed on its sides since that increases the degree of restraint which increases the stress level. Two sides and both ends fixed increases the stress by a factor of $1/(1-\nu)$ (ν is Poisson's ratio) $= 1/(1-0.33) = 1.5$. All four sides and both ends fixed increases the stress by a factor of $1/(1-2\nu)$ or $1/(1-0.67) = 3$.

The temperature results as previously determined are used as inputs to the stress analysis program. The relations representing the equilibrium of each element and the conditions for continuity between the elements are solved directly. The normal stresses s_x and s_y and shear stress s_{xy} in the plane of the cross-section are computed for each element and the axial stress s_z is determined from the expression

$$s_z = \nu(s_x + s_y) - E\alpha T \quad (\text{for fixed ends}). \quad (3)$$

where ν is Poisson's ratio, E is the modulus of elasticity, α is the thermal expansion coefficient, and T is the temperature change of element.

By combining s_x , s_y and s_{xy} the in-plane principal stresses s_1 and s_2 (maximum and minimum normal stresses) are determined for each element by means of the expression.

$$s_{1,2} = \frac{s_x + s_y}{2} \pm \left(\left(\frac{s_x - s_y}{2} \right)^2 + s_{xy}^2 \right)^{1/2}. \quad (4)$$

The absolute values of principal stress differences $|s_1 - s_2|$, $|s_1 - s_z|$ and $|s_2 - s_z|$ are computed and the maximum of the three is compared to a design stress. Typically the axial stress s_z is largest compared to s_1 or s_2 and is at the point of maximum copper temperature (point A in fig. 4). The advantage of fixing the ends is that for a constant thermal moment at each section, counteracting equal moments are developed at the ends resulting in no absorber displacement. The product of

Fig. 4. Stress components: plane-strain analysis.

s_z and the area on which it acts ΔA_{ax} is the axial force on each element and when summed across all elements is the axial restraining force on the absorber. In addition, this elemental axial force when multiplied by its distance to each of the two neutral axes and summed over all elements results in the previously mentioned restraining moments acting on the ends of the absorber. The program determines the stresses when one end is fixed and the other is free by applying the fixed ended elemental forces and moments of opposite sign to the ends of the absorber. The resultant maximum stress

Table I
Stresses, deflections and reactions - fixed/free end conditions

		Horizontal absorber at 6° 24" long				Vertical absorber (splitter at 2°, 24" long	
		Both ends fixed		One end fixed, one end free		Both ends fixed	One end fixed, one end free
Photon beam positions figure number		2a	2b	2a	2b	3b	3b
F_{ax}	lb	3430	3760	0	0	8590	0
M_{ax}	lb in.	138	110	0	0	322	0
M_{ay}	lb in.	0	390	0	0	0	0
s_{max}	psi	15700	20000	5970	6600	25500	2000
δ_{max}	in.	0	0	0	0.16	0	0
δ_{max}	in.	0	0	0.13	0.10	0	0.085
θ_{max}	deg	0	0	0.62	0.50	0	0.22
θ_{max}	deg	0	0	0	0.80	0	0

values for an absorber with a free end are about 1/3 to 1/12 of the fixed ends values and do not occur at the point of maximum copper temperature but typically at the water channel wall on the side away from the photon beam (point B in fig. 4). Table 1 summarizes these results. The resultant absorber displacements (deflections and slopes: 0.160" and 0.8° maximum) for the fixed/free condition are large. Due to the configuration of the absorber (the two loops at each end acts as compliant structural members – see fig. 1), one end constraint can be adjusted (the other end being fixed) by shifting the position of the support section near the loop to optimize the stress/displacement characteristics.

The upstream end is fixed because the slight beam incident angle increase near the fixed end due to the thermal heating is less than if the downstream end was fixed. The angle increase should be minimized as it results in greater power density on the absorber.

4. Absorber stress/deflection analysis

A finite element beam-frame stress analysis program was utilized to determine stresses and displacements of the actual absorber. This method requires inserting the axial force and moments, as determined from the fixed ends solution, into the frame at the location corresponding to the two ends of the power input section (see fig. 5).

The applied axial force and moments redistribute themselves throughout the frame depending on the geometry, elasticity and boundary conditions of each finite element beam with the resultant axial force, F_{ax} , moments M_x , M_y , and displacements (3 translation, 3 rotation) at each beam being determined. The resulting axial stress s_z is determined by the following expression

which combines the axial and bending stresses.

$$s_z = \pm \frac{F_{ax}}{A_{ax}} \mp \frac{M_x}{I_x} x \pm \frac{M_y}{I_y} y,$$

where F_{ax} is the axial force at each section, A_{ax} is the axial cross-section, M_x , M_y are the moments about orthogonal axes, I_x , I_y are the moments of inertia about orthogonal axes, and x , y are the distances of the element from the respective neutral axes.

This resulting value of s_z is now combined with s_1 and s_2 as previously determined from the plane-strain analysis to determine the actual principal stress differences as before and the maximum of these is compared to the allowable thermal stress. There are two basic types of thermal stresses. One type causes excessive distortions of the entire structure and the allowable stress is twice the annealed OF copper yield strength (2 times 8000 psi) [9]. The other produces no significant displacements and fatigue strength is used as a criteria for failure since thermal cycling will occur during normal operating procedures.

For a ten year life, a conservative value of 10^5 cycles (40 times a day $\times$ 250 days/y) was assumed. A number of sources [5–8] were used to determine actual test failure levels of stress of annealed OF copper for various cycle times. A conservative value of stress failure level was used and a safety factor of 2 was applied to determine the design stress. At 10^5 cycles the design single amplitude is 7500 psi. The computed maximum principal stress difference was compared to the stress range (double amplitude) or 15000 psi. This is the basic procedure followed by the ASME Pressure Vessel Code in designing pressure vessels for fatigue [9].

Fig. 6 shows the resultant values of moments, axial forces, stresses, and displacements for a typical absorber positioned in the horizontal plane and a beam splitter positioned in the vertical plane.

Fig. 5. Stress analysis: beam-frame model

Fig. 6. Resultant stresses, displacements and reactions: (a) 6° horizontal absorber. (b) 2° vertical absorber.

Work done at Brookhaven is supported by the Division of Materials Sciences, U.S. Dept. of Energy, under contract DE-AC02-76CH00016.

References

- [1] W. Thomlinson, X-ray Power Distribution from Multipole Wiggler Magnets (April 1983) internal memorandum.
- [2] W.H. McAdams, Heat Transmission (McGraw-Hill, New York, Maidenhead, 1942) p. 219.
- [3] D. Burgreen, Elements of Thermal Stress Analysis, 1st ed. (C.P. Press, 1971) p. 137.
- [4] F.L. Singer, Strength of Materials (Harper and Bros., 1951) p. 299.
- [5] A Survey of Properties and Applications, OFHC Brand Copper, Amax Copper, Inc. 1270 Ave. of the Americans, NY, NY 10020, USA.
- [6] A. Blatherwick, and D. Mowbray, ASTM Proc. 64 (1964) p. 561.
- [7] J. Tavernelli and L. Coffin, ASME J. Basic Eng. (Dec 1962) 533.
- [8] Standards Handbook, Alloy Data, Copper Development Association, Inc. 405 Lexington Avenue, NY, NY 10007, USA.
- [9] ASME Boiler and Pressure Vessel Code, Section VIII, Division 2, 1982.

THE SUPERCONDUCTING WIGGLER BEAMPORT AT THE NATIONAL SYNCHROTRON LIGHT SOURCE

W. THOMLINSON, D. CHAPMAN, N. GMÜR and N. LAZARZ

National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York 11973, USA

A beamport is currently being instrumented to utilize high energy synchrotron radiation from the superconducting wiggler magnet on the X-ray ring at the National Synchrotron Light Source. Two independent programs are being developed to run in tandem, nonconcurrently, on the central beamline: material sciences on X17B1 and medical research angiography on X17B2. A high pressure research program will run independently on a side station X17C. Considerations in the design of the beamline include handling severe power loading, radiation shielding protection and beam energy filtering.

1. Introduction

The X17 beamport at the National Synchrotron Light Source is currently being instrumented to take advantage of the high energy synchrotron radiation from the superconducting wiggler (SUW) insertion device. The principle spokesperson for this project is Dr. William Thomlinson, NSLS. The original beamline layout and design parameters were specified in the NSLS Superconducting Wiggler Beam Line (X17) Conceptual Design Report, March 1984 [1]. The experimental programs proposed by the X17 Insertion Device Team (IDT) will utilize the high energy and high flux from the SUW. The superconducting wiggler magnet can provide useful photon fluxes at energies up to 100 keV.

X17B1 and X17B2 experiments will run in tandem, nonconcurrently, while the side station X17C will run independently. The X17B1 program is dedicated to material sciences research, utilizing white beam or monochromatic beam for crystallography, EXAFS and topography. The principle spokesperson for this project is Dr. Dean Chapman, NSLS. Downstream from X17B1, the X17B2 program is designed for medical research, principally angiography [2]. For this program, a medical suite has been built as part of the NSLS Phase II construction project to accommodate physicians, patients, scientists and computers. Dr. Edward Rubenstein, Stanford University Medical Department, is the angiography program's principle investigator [3,4]. The X17C IDT is currently designing a program which concentrates on high pressure research. Dr. Earl Skelton of the Naval Research Laboratory is the program's spokesperson.

2. Source parameters

Commissioned in 1984, the NSLS X-ray ring achieved 2.5 GeV in August 1985. The ring operates at currents over 200 mA with lifetimes of 8-12 h at 100 mA. By 1988, approximately 30 beamports will be utilized and 54 beamlines will be operating or under commissioning.

A total of five insertion devices are planned for installation into the NSLS X-ray ring, including the X17 SUW. Fig. 1 shows a photograph of the SUW magnet prior to installation. The operation of the SUW at 5 T magnetic field, and its effective six poles, will result in a photon operation with higher critical photon energy (20.8 keV), higher photon flux, and higher available photon energy (up to 100 keV) than the arc sources. Fig. 2 presents the calculated spectrum for the SUW beam line. Important SUW parameters are given in table 1 [5].

The SUW maximizes current density by using two winding layers in the superconducting NbTi conductor coil package [6]. There are two coil assemblies per pole with the poles and outside structure made of iron. Original magnet testing in 1983 achieved 6 T. Recent magnet tests, on and off the central axis, have been conducted by NSLS staff members. These tests were completed to ascertain the effects of the SUW on the electron beam and to investigate the field characteristics of the magnet. Results showed that a peak field of 5.2 T at 215 A could be achieved regularly without quenching. Reaching higher fields increases the probability of a quench as does using ramp rates greater than 0.2 A/s [7].

Fig. 1. Superconducting wiggler magnet (SUW) prior to installation into the magnet housing

A major concern is controlling the power load and thermal problems associated with the high energy SUW beam. Thermal analysis and stress calculations by NSLS engineers established the design criteria of the front end water cooled aperture/splitter assembly and the front end safety shutters. Analysis of beam motion during

ramping and operations is currently being considered in the design of the exit chamber from the storage ring and the magnet bore tube.

Table 1
SUW parameters

Device parameters				
Pole – full field	5			
– half field	2			
Period length	17.4 cm			
Gap	3.2 cm			
Magnetic field	5 T			
Operational parameters				
Maximum wiggler				
field (T)	5	5	5.4	5.4
Ring energy (GeV)	2.5	2.8	2.5	2.8
Min bending radius (m)	1.67	1.87	1.54	1.73
Critical energy E_c (keV)	20.8	26.1	22.4	28.2
Deflection parameter K	80.9	80.9	87.4	87.4
Horizontal opening				
angle (mrad) on-axis	33.1	29.5	35.7	31.9
vertically-integrated				
power density				
(W/(mrad mA))	2.0	2.81	2.16	3.03
Total power (W/mA)	46.6	58.4	54.3	68.2

Fig. 2. High energy spectrum for the superconducting wiggler magnet (six poles, 5 T). Beamline X17, calculated for an X-ray ring energy of 2.5 GeV

Fig. 3. (a) Schematic (X17 Beamline) front end (b) Schematic (X17 Beamline) shield wall to X17B1 hutch (c) Schematic (X17 Beamline) X17B1 hutch to X17B2 experimental area. The distances of components in (a)–(c) are measured in millimeters from the last pole of the SUW

A liquid helium cryogenic system will be used to refrigerate the SUW. A separate cryogenic building has been constructed to house the system with a direct connection to the SUW through the roof of the X-ray ring tunnel. Designed, built and tested in 1983/84, the system is currently being retested, mated with the SUW, and hardware/software integrated with two micro-processors. Continuous computer monitoring of the system will help ensure a steady-state operation and will keep the beamline and NSLS Control Room up-to-date on the status of the cryogenics and the magnet.

3. Beamline components

The X17 beamport comes off the X-ray ring at 0° to the dipole magnet and has a maximum beamline length of 40 m from the source, considered to be the last pole of the SUW magnet. Figs. 3a–3c show a schematic of the beamline. A water cooled crotch assembly separates X17 and X18 as well as protects downstream valves and flanges from dipole radiation. With the SUW operating at 5 T, a total radiation fan of 33.1 mrad exits from the magnet. The storage ring vacuum chamber walls are bathed in radiation and absorb about 18.1 mrad of the horizontal radiation fan. This leaves about 15 mrad of

beam which enters the front end aperture/splitter assembly.

3.1. Beamline mask and valves

Located 8.04 m from the source, a water-cooled mask protects the downstream flanges and valves from dipole radiation. The vacuum integrity of the system is protected by a UHV valve and a modified 30-mm vertically-opening fast valve. The pneumatically operated UHV valve can close within 2 s of a vacuum failure and the fast valve within 8 ms. Neither the mask nor the valves can withstand SUW radiation thereby necessitating a beam dump if they are in the closed position when the SUW is operating.

3.2. Beam position monitor

A beam position monitor, similar to a design developed by the Lawrence Berkeley Laboratory and used on Beamline VI at the Stanford Synchrotron Radiation Laboratory [8], is placed at 8.58 m from the source. The NSLS monitor consists of two molybdenum blades, $38 \times 32.5 \times 0.25$ mm, which establish the vertical beam position by measuring the difference current of photo-emission electrons ejected from the blades. The blades

Fig. 4. X17 aperture/splitter assembly.

are moved into position above and below the beam, where they remain during operations, by remotely controlled actuators. If the beam is too high or too low, a higher electrical current is read from the upper or lower blade and the beam position is modified accordingly. A heat pipe, cooled by a close loop water-filled heat exchanger, conducts the heat away from the blades [9]. A beryllia sleeve surrounds the heat exchanger to electrically isolate the heat pipe from the cooling water [10].

3.3. Front end aperture / splitter assembly

Approximately one year of engineering work and one year of designer effort went into the design of the front end apertures. They act not only as apertures for X17A, B and C, but also as the primary beam splitters between the branch lines and the primary synchrotron radiation photon shutters for all three lines. Fig. 4 is a photograph of the aperture/splitter component in the assembly stage prior to being enclosed in its housing.

The aperture absorbers will be positioned at an angle in the beam in order to increase the exposed absorber surface area and to reduce the high power density per unit absorber length associated with the SUW beam. The absorbers are rectangular OFHC copper tubes, $\frac{3}{8}$ in. thick $\times$ 1 in. wide with a $\frac{3}{8}$ in. water channel, which sit in the beam at a 6° horizontal grazing angle. To control the 406 W/cm^2 power density in the absorbers at 10 m from the source, the required water cooling would be 7 gpm with a maximum cooling wall channel temperature of 66.4°C [11].

The front end aperture assembly consists of a set of vertical apertures, two beam splitters and three beam shutters. The vertical absorbers define the vertical source size up to 1.5 mrad (± 0.75 mrad) for the full incident 15 mrad beam. Sitting at 6° to the beam, the absorber length is 774.7 mm at 11 m [12].

Two 2 mrad wide beam splitters permanently sit directly downstream of the vertical apertures at a 2° angle to the beam. The splitters allow 5 mrad down the central B line, cut off 2 mrad on either side, and allow 2.3 mrad down the outside A and inside C beamlines. A non-uniform power distribution hits the splitters with a maximum power per unit length of 343 W/cm [11].

The individual absorbers are mounted to the frame, outside of the housing, while the stainless steel housing itself is "free-floating" through an innovative bellows arrangement. This design was used to protect and preserve the aperture and splitter alignment from any structural motion of the housing associated with bakeout or vacuum changes.

Downstream from the splitters, there are three water cooled photon shutters, two horizontal and one vertical. These shutters are the primary beam stoppers and must be in the closed position when the front end safety shutters, beamline safety shutters, or any downstream

valves are in the closed position or when entry into the radiation tunnel or hutches (white beam mode) is required. Currently the X17A line is shuttered closed, awaiting proposals for development. The photon shutters are pneumatically driven, as opposed to using stepper motors, a design based on safety and reliability considerations.

3.4. Filter assemblies

A filter assembly, at 12.5 m from the source, consists of 18 graphite foil filters, two beryllium windows and an experimental gas filter. This assembly is placed in the beamline to reduce beam power to acceptable levels for experimental programs and beamline optics. The graphite filters, with a total thickness of 0.391 mm, attenuate the soft X-ray flux so that beryllium windows may be inserted in the line. A similar filter assembly, designed by the Lawrence Berkeley Laboratory Design Group, has been successfully used at the Stanford Synchrotron Radiation Laboratory on Beamline VI [13].

Just slightly downstream, two 0.254 mm thick beryllium windows enclose a 180 mm long gas chamber which can be maintained at 0–1 atm pressure of an inert gas such as xenon or krypton. The beryllium and gas act as filters which attenuate the low energy photons and will decrease the total power on the first monochromator crystal by a factor of five.

3.5. Front end safety shutters

The front end safety shutters for the three beamlines can be operated independently. Located 13.3 m from the source, the safety shutters are the last front end component before the beamline exits from the front end shield wall. Three heavymet (tungsten alloy) shutter blocks, 6 in. long, sit in line with the A, B and C beams. The blocks move vertically in and out of the beam, 1 in. in 15 s. They are not water cooled and therefore cannot be inserted into the direct SUW beam. To prevent this, the front end photon shutters must be in the closed position before the blocks are dropped into the beam. Additional tungsten inserts are positioned between the A, B and C beams, directly downstream of the shutter blocks to help in eliminating possible bremsstrahlung radiation crosstalk between the beamlines.

4. Beam transport components

4.1. Beamline beam position monitor

The beamline exits the shield wall 14 m from the source. At 20.15 m, a beam position monitor will check the exact position of the beam and have the ability to close the photon shutters if the beam exceeds preset

limits. The monitor will be remotely controlled and must be able to withstand the high power of the SUW beam.

4.2. Beamline apertures

Downstream from the monitor at 21.27 m from the source, beamline apertures further define and clean up the beam prior to entry into the B1, B2 and C experimental hutches. These copper absorbers set the height and width of the beam individually for the B and C beamlines. A set of two vertical absorbers, one above and one below the beam, will independently define the vertical height of the beam from 0 to 1.5 mrad for the B and C beamlines.

Directly downstream, a set of two "flipper-like" absorbers will define the beam horizontally for B and C by swinging into the beam from either side. The B line can be adjusted from 0 to 5 mrad and the C line from 0 to 2.15 mrad.

4.3. Material sciences monochromator

A monochromator for use by the material sciences program is located at 22.8 m from the source. Forecast to be installed in the beamline in 1988, the "day-one" two crystal monochromator will be used to provide monochromatic beam to the B1 program, as well as for thermal analysis for the next generation focusing devices.

The monochromator carriage has a kinematic mount which can vertically move the crystals out of the beam with a 15 mm offset. This allows the full 5 mrad white beam to pass directly through the monochromator and B1 hutch and into the B2 monochromator. As a result, the B1 material sciences program is able to run in either monochromatic or white beam mode. Two Si (111) crystals will be used with a 2° to 26° Bragg angle range and a 4.5–56.7 keV energy range. The first crystal can rotate while the second crystal can rotate and move horizontally. Beam acceptance of the monochromator will be 2 mrad horizontal.

Crystal cooling is a very important component of the monochromator design. The direct incident beam power density, after filters, with the storage ring running at 2.5 GeV, 500 mA and the SUW at 5 T, is calculated to be 750 W/horizontal mrad. A finite-element, engineering software program is currently being used to calculate the thermal profiles. A temperature or pressure sensitive direct beam emergency monitor will be placed behind the first monochromator crystal. This monitor can activate safety procedures if the crystal fails, falls off the crystal mount or if the beam misses the crystal altogether.

4.4. Beamline safety shutters

The beamline safety shutters are directly downstream from the monochromator, 24.11 m from the source. Operating independently, two heavy metal blocks sit directly either in or out of the B or C beams. The main purpose of the shutters is bremsstrahlung radiation protection when entry into the B1, B2 or C hutch is required. These shutter blocks cannot withstand the direct SUW beam, so either the front end photon shutters must be closed or the beamline must be in monochromatic mode for the blocks to be in the down position. The shutters also protect against bremsstrahlung radiation crosstalk between the B and C beamlines when entry into the B or C hutch is required and the other beamline is operating.

4.5. Beamstop

A beamstop is currently in fabrication for the X17B1 hutch. The component consists of eight copper water-cooled absorbers which sit at a 15° angle to the beam and which are enclosed in a $\frac{1}{4}$ in. lead housing. The absorbers' main purpose is to intercept the beam before entering the X17B2 area when the material sciences program is operating. 8 in. lead bricks behind the copper absorbers give a 2 in. overlap on all four sides of the beam profile and provide for bremsstrahlung radiation shielding. The beamstop manually slides in and out of the beam path on a track. The entire assembly is interlocked into place before beam is allowed into the X17B1 hutch.

5. Shielding

5.1. Radiation calculations

A computer program, FILTER, was originally developed by Suortti and Thomlinson in 1984, to calculate the resulting photon flux as a function of energy and vertical angle when filters or absorbers were placed in the beam path [14]. This program, renamed PHOTON, was modified by Chapman et al. in 1987 [15].

The main purpose of modifying the program was to ascertain the amount of shielding required on the X17 beamline as a result of the high energy spectrum associated with the SUW beam. Calculations were run to determine the required shielding in the front end, by using the copper absorbers in the aperture tank as a source of scatter, and around the beam line itself by using the Si crystals in the monochromator as the main scatter source.

Experiments were carried out to verify the radiation calculations. The setups involved measuring the actual dose readings with a dosimeter, from several scatter

sources, through successively thicker sheets of lead. Photons with energies up to 10 keV were scattered off materials such as germanium, tungsten and silicon. The results showed that the calculated doses were consistently higher than the measured doses by a factor of between 2 and 8 but with a correct energy and geometrical dependence [16,17]. These discrepancies were probably a result of the linear polarization of the incident photon beam combined with the fact that the dose was measured in the horizontal plane at 90° to the scatter source. The program was modified to more accurately reflect true experimental data.

5.2. Radiation shielding

Radiation dose calculations showed that the storage ring front end, beamline and hutches would have to be heavily shielded. For example, high potential radiation dose values were calculated within the unshielded X-ray ring tunnel at 1.5 m from the source where it was found that 1.2×10^9 mrad/h could be expected. In the front end, $\frac{1}{4}$ in. lead sheet will be wrapped as close to the beam pipe as possible and placed within the quadrupole and dipole magnets where accessible. This will help control the scatter within the X-ray tunnel itself as well as help control the high levels of ozone expected with SUW beam.

Most of the beamline, outside of the shield wall, will be enclosed in an 8 ft high radiation shielding tunnel. The tunnel will be made of sandwich panels composed of $\frac{1}{8}$ in. steel - $\frac{1}{4}$ in. lead - $\frac{1}{8}$ in. steel. The panels will be removable for ease in moving and accessing equipment. The B1 and C hutches and B2 monochromator room will also be constructed out of the same sandwich panels. Individual components such as the monochromator, may require additional shielding as indicated by real-time radiation measurements during beamline commissioning.

6. Experimental programs

The X17B1 material sciences program will be used for experiments such as scattering, crystallography, EXAFS, topography and high pressure work. The large B1 experimental area and hatch provides for the easy exchange and access of apparatus. The experimental equipment, currently being assembled includes a six-circle Huber diffractometer on a kinematic mount, a lift table and computer controlled CAMAC data acquisition system. This program is allocated 75% of the operational beam time with the other 25% reserved for the X17B2 program.

The medical research program on X17B2 will initially concentrate on digital subtraction angiography. This research is a collaborative effort between the NSLS

and the Stanford University Angiography Project at SSRL [3,4]. Taking advantage of a dedicated synchrotron source, the availability of a high energy photon flux from the SUW, and a commitment to build a medical research facility, the angiography program at SSRL is slated to move to the NSLS in late 1988 [2].

The angiography program is developing a diagnostic procedure using digital subtraction to image restricted or diseased coronary arteries. A dual energy monochromator will provide energies above and below the contrast agent (iodine) K-absorption edge. A 600-element detector will record images which, when digitally subtracted, provide a high resolution picture of the coronary circulation.

Currently under development, the X17C program is geared toward high pressure physics research. A white-beam energy-dispersive diffraction system will be used to investigate the structure / phase of small samples in a diamond anvil cell.

References

- [1] W. Thomlinson, BNL Informal Report 36050 (1984).
- [2] W. Thomlinson, N. Gmür, H.D. Zeman, J. Otis, R. Hofstadter, A. Thompson, G. Brown, E. Rubenstein, J. Giacomini, H. Gordon and R. Kernoff, submitted to the International Meeting on Synchrotron Radiation Applications to Digital Subtraction Angiography, Laboratori Nazionali di Frascati (1987), BNL Report 39792 (1987).
- [3] E. Rubenstein, R. Hofstadter, H.D. Zeman, A. Thompson, J. Otis, G. Brown, J. Giacomini, H. Gordon, R. Kernoff, D. Harrison and W. Thomlinson, Proc. Natl. Acad. Sci. USA 83.
- [4] A. Thompson, R. Hofstadter, J. Otis, H.D. Zeman, R. Kernoff, E. Rubenstein, J. Giacomini, H. Gordon, G. Brown and W. Thomlinson, these Proceedings (5th Nat. Conf. on Synchrotron Radiation Instrumentation, Univ. of Wisconsin-Madison, 1987) Nucl. Instr. and Meth. A266 (1988) 252.
- [5] D. Chapman, N. Gmür, R. Greene, N. Lazarz and W. Thomlinson, X17B Insertion Device Progress Report 87-01 (1987).
- [6] H. Hsieh, S. Krinsky, A. Luccio, C. Pellegrini and A. Van Steenberg, Nucl. Instr. and Meth. 208 (1983) 79.
- [7] G. Decker and J. Galayda, NSLS, Private Communication (1987).
- [8] D. Hunt, LBL Beam Position Monitor Assembly Drawing, LBL 20L3986 (1982).
- [9] S. Sharma and M. Woodle, these Proceedings (5th Nat. Conf. on Synchrotron Radiation Instrumentation, Univ. of Wisconsin-Madison, 1987) Nucl. Instr. and Meth. A266 (1988) 513.
- [10] M. Howells, P. Mortazavi, M. Woodle, H. Rarback and D. Shu, Nucl. Instr. and Meth. A246 (1986) 417.
- [11] S. Sharma and S. Uic, Nucl. Instr. and Meth. A246 (1986) 423.
- [12] S. Sharma and S. Uic, BNL Informal Report 34314 (1987).
- [13] E. Hover, LBL Engineering Note M6570A (1986).

- [14] P. Suortti and W. Thomlinson, BNL Informal Report 34934 (1984).
- [15] D. Chapman, N. Gmür, N. Lazarz and W. Thomlinson, these Proceedings (5th Nat. Conf. on Synchrotron Radiation Instrumentation, Univ. of Wisconsin-Madison, 1987) Nucl. Instr. and Meth. A266 (1988) 191.
- [16] E. Brauer and W. Thomlinson, BNL Informal Report 39541 (1987).
- [17] E. Brauer and W. Thomlinson, these Proceedings (5th Nat. Conf. on Synchrotron Radiation Instrumentation, Univ. of Wisconsin-Madison, 1987) BNL Report 39793, Nucl. Instr. and Meth. A266 (1988) 195.

Abstract

Design principles for radiation safety systems are presented. The safety systems at the NSLS are described and experience recounted.

Introduction

At the National Synchrotron Light Source in early 1987 there were 55 beam lines in operation, some with more than one experimental station. The majority of these beam lines have been designed, constructed, and managed by Participating Research Teams (PRT's) whose institutional affiliation and funding is from outside the NSLS. The PRT members are the principal users of their beam lines, but 25% of the research time is allocated to general users who apply to the NSLS for use of the facility. There are also a few lines which are operated by the NSLS and dedicated to general users. During fiscal 1986 there were over 800 registered users of the NSLS, and about 430 separate experiments were performed. The research carried out covers a wide range of disciplines, including atomic physics and biology, medicine and metallurgy, with scientific objectives ranging from pure research to proprietary industrial development. The users come from a wide variety of backgrounds, and some are not experienced at working at large facilities like the Light Source.

These factors have influenced the development of radiation safety systems at the NSLS. Careful integration of operations procedures and administrative controls with the personnel interlock systems has been needed to keep pace with increasing research activity.

Philosophy

Interlock Design Principles

The design principles discussed below have been developed during several years experience in the design, construction, and use of radiation safety systems at the NSLS and other facilities. No attempt has been made to list them in order of importance.

1. The system should be unrestrictive.
2. The system should be ergonomic.
3. The system should be redundant.
4. The redundant branches of a system should be different.
5. The system should be fail safe.
6. The system should be testable.
7. The system should be simple.

There are of course conflicts among these principles, and a final design must be a compromise.

The first rule is supported by the general idea that the need for a safety system comes up only because the research is worth doing in the first place. The system designer should not accept compromises to safe operation, but it is well to keep in mind the purpose of the institution. Apart from this, there are operational reasons for minimizing the restrictions of a safety system. Perhaps the most important is credibility. If a safety program has a reputation for being "no-nonsense", if convincing arguments can be made that each barrier protects against real danger, then users are likely to respect and accept the restrictions. Having said this, we arrive at compromise. Often restrictions are extended beyond what is needed in specific cases for reasons of sim-

plicity, both in hardware and administration, and for standardization. These extensions should be recognized as compromises and justified as such.

Ergonomic design is a matter of enlightened self interest. The avoidance of mistakes and blunders in the operation of a system is clearly an enhancement to safety. Also the safety of the experimental activities at a research facility depends largely on the cooperation of the users. An experimenter who has been wrestling with an awkward, balky, overly restrictive safety system is unlikely to be in a mood to cooperate.

The dictionary definition of redundant is "exceeding what is necessary or normal". With respect to interlock systems this is often taken to mean the duplication of active components. A better functional definition of a redundant system is one "where no single failure will render the system unsafe". To meet this definition, the redundant branches of an interlock circuit must have no common elements. The use of redundant systems can provide a large decrease in the incidence of unsafe failures in an interlock. If we estimate the frequency of single failures to be one per 20 years per system, and the interval between tests and hence the correction of a fault to be 6 months, then there would be a coincidence of two failures in a system every 800 years.

The calculations which show the advantages of redundant interlocks assume that failures will be random and unrelated. If the two branches of a redundant system are identical, there is a good chance that there will be related simultaneous failures, defeating the redundant protection. The qualities which can lead to related failures include the use of similar components, similar arrangements of logic, symmetrical location of terminal points on terminal strips, common power supplies or common reference points, and many other such features. The possibility of related failure brings a large reduction in system safety, and the avoidance of this deserves substantial design effort. Often this means that one of the alternate branches may not be optimum in terms of components or function. This is part of the overall compromise and must be evaluated as such.

A fail safe design is one in which the most likely failure modes leave the system in a safe condition. For example, loss of power, shorts to ground, and open circuits should all leave the system in a safe state. Determination of common failure modes comes from experience and engineering analysis. In most cases the objective is to reduce serious failures to a very low incidence, and it may be difficult to accumulate significant experience in a reasonable time. On the other hand, an analysis depends on knowledge of the details of the system and this may be difficult to obtain. For example, integrated circuit logic outputs may fail either open or shorted, depending on the nature of the stress and on manufacturing details which may not be part of the chip specification. Microprocessor systems are even less accessible to detailed failure analysis. Computer hardware bugs are seldom understood in detail. Sophisticated accelerated endurance tests can be devised, but there are lingering doubts about the final interconnected system in the operating environment. Since the issue of related failures can have a powerful effect on system reliability, such doubts weigh heavily. The aerospace industry has shown that such systems can be built, but at great expense. These considerations had a dominant influence in the choice of relay logic in

CH2387-9/87/0000-1605 \$1.00 © IEEE

the NSLS interlock systems, anachronistic as it may seem.

System testing is probably the single most important contribution to safe operation. The largest source of faults come from wiring errors which occur during construction and maintenance. Construction errors are expected, and are sorted out during the informal testing as a system is commissioned. Faults which arise during maintenance are more subtle, and experience has shown that the definition of maintenance must be broad. At the NSLS, a system must be tested whenever a circuit element inside the enclosure for the system logic has been touched. The history of selected failures at the end of this paper supports this policy. The encouragement of neatness and care is worthwhile for an efficient construction enterprise, but to expect perfection is hopeless. In any case, testing must be done for faulty components (and flawed design).

The test should include all of the protective elements of the system and verify their function. Each element of redundant features must be checked, and this capability must be part of the system design, since it is common for the action of one element to mask the effect of the other. The test should not only verify that the system works as expected, but also that improperly executed operations do not lead to unsafe conditions. In designing tests and interpreting the results, it is important not to rely too heavily on the system logic, since this is one of the things being tested.

Simplicity is a virtue which appears in this discussion as part of the compromise that each actual system represents. When a choice must be made between covering all conceivable possibilities, and simplicity, the latter should prevail. Sometimes excessive extensions or layers of protection in a safety system represent uncertainty or lack of knowledge of the problem. The pronouncement "You can't be too safe..." often means that safety measures have been carried past the point of counter-productivity, that the hazard is not well understood, and that there is a lack of confidence in the basic safety system.

Administrative Controls

Hardware interlocks are appropriate for protection against hazards where the risk is high, or where mistakes are likely to occur as the user interacts

with the system. In other cases safety can be maintained with administrative controls: procedures, rules, and sanctions. Most of the safety system design principles listed above apply as well to administrative controls, although in a less precise way. The avoidance of unnecessary restrictions, ergonomic design, and simplicity certainly apply. There needs to be backup supervision of performance, and an audit function, both periodic and after any breakdowns. The approach is clearly similar. Sanctions are necessary, but are difficult to apply. If they are too severe, violations are often overlooked, or let off with a warning, so less is better if this leads to consistent response to violations. In severe safety violations, the punishment must be appropriate, for example revocation of research privileges. A vital part of administrative control is the services of a skilled, disinterested operator (known at the NSLS as the Operations Coordinator). This person keeps track of experimental activities, monitors compliance with safety procedures, and serves as a resource in dealing with interlock, vacuum, and other user problems.

Description

Injector and Storage Ring Safety Systems

The interlock system logic is shown in Fig.1. Shutters serve to partition the four areas from each other. For example, if the injection shutters to the VUV ring and the x-ray ring are closed, then injector operation does not depend on the state of those systems. The interlocks for the injector and the x-ray ring are similar. One branch of the redundant system consists of door-closed switches, emergency stop buttons, and the search sequence. The other branch is a Kirk lock captive-key system which mechanically locks the doors and closes an electrical circuit when all keys are in place in the security system. The redundant branches are separate and act independently to shut down the radiation source if a system is breached. The VUV ring is not a high hazard radiation area, and the interlock for the center part of the ring serves only to control access to this area.

Figure 1. Interlock System Logic.

The energy spectrum of the synchrotron radiation in the x-ray beam lines extends to a few tens of kilovolts, and a millimeter of lead or a few millimeters of steel are usually an adequate shield. However, the radiation intensity in the beam is of order 10^{10} Rads/hour, and would cause instant serious injury, so the means of containment must be very secure. The beam lines also represent a hole in the storage ring shielding, so bremsstrahlung shielding must be provided along the beam line.

Most x-ray beam lines and in a hutch which houses the experiments. This is a structure made of 1/8 inch steel, is typically two or three meters on a side, and is provided with overlapped seams, shielded view ports, and an interlock system. Some experiments require user access to the hutch 20 or more times an hour, so the interlock must be simple to operate, reliable, and fool proof. The user performs these accesses to the hutch, and also searches and returns to beam-on condition without intervention from the operations staff. Chain A of the beam line interlock is implemented with relays which provide sequencing and indicators as well as the interlock. Chain B uses only the various switches wired to provide the required logic, and thus is physically quite different from Chain A. Not shown on the logic diagram are the circuits which prevent opening a shutter when the hutch is open or opening a door when the shutter is open thus dumping the storage ring. These are considered convenience features and not fundamental parts of the protection system.

Because of the extremely high radiation levels inside the x-ray beam lines, access to these lines must be controlled as carefully as it is to the hutches.

Padlocks are used to lock the flanges on the lines so they are not opened in an uncontrolled way. This provides protection against the situation where a worker dismantles the wrong beam line due to confusion or misdirection. Obtaining the key to the padlocks has two results: it brings an Operations Coordinator to the scene who is familiar with the implications of opening a beam line, and the padlock key is attached to another key which disables the beam line interlock. The padlocks are provided in sets which are keyed the same, with a given set confined to a beam line.

Administrative Controls

Because of the large number of beam lines and the steady parade of new experiments and users, it has been necessary to formalize some of the administrative controls. Each beam line has a written description of the configuration of the line as it was approved in the formal safety review. This is in the form of a check list with each required item of shielding, exclusion zone, padlock, and the like. Photographs are often posted on location to aid in the description. This check list is executed before any new experiment is started, and before the line is reset after it has been locked out. An Experimental Safety Approval form is filled out by the user for each experiment and lists the nature of the experiment, the personnel, and the materials and equipment to be used. Most experiments are arranged directly with the Participating Research Teams at the beam lines, and the Safety Approval form is the only required notice to the Light Source. It is reviewed for hazards by the NSLS Safety Officer and the approved form must be posted at the beam line when the experiment is running. There it helps the Operations Coordinators to keep track of what is happening on the floor, who is there, and when the experiments change.

The radiation safety systems at the NSLS have operated for several years with no dangerous failures. However, much can be learned from the history of partial failures. The largest number of interlock faults and failures are found after construction or maintenance on a system, and serve as a constant reminder of the need for a rigorous testing program. Two such faults are particularly interesting. The first occurred after several new beam lines were added to the x-ray ring interlock. The test found that about half of the existing beam lines no longer affected the ring interlocks when they were tripped. The problem was that 24 volts was being fed into the circuits from a power supply at one of the new beam lines due to a wiring error. These supplies are supposed to float so they can't crosstalk, but the one at the beam line was grounded by another wiring error, and the ones in the ring circuit were grounded at faulty indicator light sockets. This failure is particularly hair-raising because an error at one beam line caused a failure at other beam lines, which might not have been tested. This situation has been corrected by more careful isolation of the power supplies, by periodic tests for ground faults, and by more vigilance for crosstalk possibilities.

The second failure was found in a test of the VUV interlock after a ring maintenance period. The assertion was that no work had been done on the system, but part of the interlock was found to be bypassed. It turned out that a technician had been assigned to attach numbers to some wires in the system, a few wires had to be pulled out to get the numbers on, and one was put back a quarter of an inch from where it came.

Recently it was discovered that the linac interlock could be left indefinitely in a partially searched state with the access door unguarded. This was due to a quirk in the circuit design and had been overlooked when the test was designed. It was found when an error was made in executing a test, and an attempt was made to reset the system by opening a door. The problem was easily corrected, and a much more careful analysis has been made of the circuit.

There have been two spontaneous, nonsafe faults in interlock systems during the last two years, when an average of 20 systems were in service. The estimate in the discussion on redundant circuits comes from this experience. One failure occurred after a jumper in an x-ray beam line interlock was removed to introduce a new interlock feature. The system passed the test at that time, but at the next periodic test it was found that the jumper, which had only been removed at one end, had moved back and was touching the terminal where it had been pulled. Jumpers are now removed at both ends. The second failure involved two faults: the power supply in a beam line interlock shorted its "high side" to ground, and a short to ground elsewhere in the system caused the shutter control circuits to be bypassed, allowing the shutter to be opened when the hutch was not secured. When this was done, both ring interlocks opened, and the storage ring dumped. The shutter control circuit is not part of the fundamental protection system, but this failure illustrates a significant failure mode.

Acknowledgements

The author wishes to thank George Schwender for the initial interlock design, Bob Best, John Gallagher and Steve Kemp for construction and installation, and Luis Aguilar, Steve Kemp, Len Pharr, Pete Ratzke, and Skip Thomas who as Operations Coordinators have kept the program running safely. Roger Klaffky, Norm Rohrig, and Bill Thomlinson contributed to many useful discussions.

BROOKHAVEN NATIONAL LABORATORY
M E M O R A N D U M

DATE: June 29, 1988 88-2
TO: DISTRIBUTION BELOW
FROM: C.M. Goggin, Cryogenic Safety Committee Secretary
SUBJECT: Minutes of Meeting, Cryogenic Safety Committee (6/29/88)

Members Present: A. Prodell (Chm.), R.J. Gibbs, R. Young, H. Schulman
(Ex-Officio), G. Tanguay, R. Thomas, F. Thornhill

Members Absent: J. Koehler

Others Attending: R. Zantopp (S&EP), J. Dunn (NSLS), M. Iarocci (NSLS)

The meeting was held in Room 64, Building 902-A. Chairman Prodell called the meeting to order at 10:08 A.M.

TOPIC 1: NSLS Liquid Nitrogen System Changes

The memo from J. Dunn to A. Prodell dated June 21, 1988 was discussed. The following list of changes were motioned and approved by the committee:

1. The operating instructions will include both disconnect procedures and connect procedures.
2. Protective equipment such as goggles and gloves will be available.
3. The oxygen sensor will activate the roll-up door, send a warning signal to the NSLS Control Room, and activate an audible and visual warning at both entrances with a sign message of "DANGER OXYGEN DEFICIENT ATMOSPHERE".
4. The filling area (tank and plumbing) will be protected from collision by forklifts with suitable barriers. J. Dunn to investigate.
5. Periodic maintenance of the oxygen sensor will be required, tags indicating the expiration date will be required.
6. J. Dunn to inquire of tank manufacturers as to the best loss rate that can be expected from the LN2 storage vessel, present lost rate is approximately 2%.

Continued—————>

CSC MINUTES (6/29/88) continued:

7. Pressure relief and bleed valves will be installed and tested with the relief valve set at 60 psi.

DISCUSSIONS

J. Dunn - noted that a pressure relief valve on the copper transfer line was needed. M. Iarocci calculated that an LN2 leak from a transfer line break could in two (2) minutes time present the danger of hypoxia to anyone in the area. Presently the exit door is left unlocked. Signs and instructions will be provided for the operators. All LN2 venting will be to the outside. There may be as much as a three month lead time on obtaining an automatic shut-off valve controlled by the oxygen sensor which is to be installed in the transfer line between the LN2 storage vessel and the building. R. Gibbs or H. Hildebrand may be able to locate one sooner. R. Gibbs will contact J. Wilcenski about the availability of a CVI valve.

R. Young - Pressure regulators should be sealed or made difficult to tamper with to prevent the settings of unsafe working pressures. The shut-off valve should be located as soon as possible. The oxygen sensing unit must be periodically checked and maintained.

H. Schulman - The retaining wall calculations should be reviewed. Operating instructions should spell out the steps for connecting and disconnecting a dewar to be filled. The calculation of the two (2) minute exposure time should be checked, the true time could be less.

A. Prodell - Trapped LN2 should not be allowed between valves on the delivery line, this line should be purged after it is used. The potential for traffic problems (fork lifts) in and around the LN2 tank and lines could result in collisions, collision barriers should be installed. The location of the oxygen sensor should consider the situation of a person who has fallen on the floor.

R. Thomas - The level of the oxygen sensor and the reaction time of the sensor should be considered when installing this unit. Safety procedures for the present installation should be in place until the filling station is finished.

R. Zantopp - The delivery line should be pressure tested. An additional alarm should be added to the NSLS Control Room, in the event of a LN2 leak.

Continued----->

CSC MINUTES (6/29/88) continued:

M. Iarocci - The LN2 storage tank may have an excessively high loss rate @ 2%. This should be researched.

R. Gibbs - Suggested the possibility of using oriface plates to regulate the LN2 flow rate, this however was generally not acceptable due to differences in flow rates at 40 psi and about 200 psi pressures.

Meeting was adjourned at 11:18 A.M.

Respectfully submitted,

Christopher M. Goggin

Christopher M. Goggin
Recording Secretary

DISTRIBUTION:

Cryogenic Safety Committee Members
Others Present
W.R. Casey
C.W. Flood, Jr.
G. Kinne
M. Knotek

CSC Recommendations Approved:

G. Kinne

G. Kinne
Associate Director

BROOKHAVEN NATIONAL LABORATORY
M E M O R A N D U M

DATE: December 22, 1986

TO: Cryogenic Safety Committee

FROM: Frank Thornhill (Recording Secretary)

SUBJECT: Cryogenic Safety Committee Minutes of Meeting
held December 11, 1986

<u>Members Attending</u>	<u>Members Absent</u>	<u>Others Attending</u>
R. Gibbs	J. Koehler	M. Brooks, HFBR
A. Prodell (Chm.)		V. Lettieri, "
A. Schlafke		P. Tichler, "
H. Schulman (ex-officio)		L. Day, S&EP
G. Tanguay		C. Weilandics, "
F. Thornhill (Secretary)		H. Hsieh, NSLS
R. Young		M. Iarocci, "
		C. Sylvester, "

The meeting was called to order by the Chairman at 1:35 P.M. Meeting was held in Conference Room 63, Building 902-A.

TOPIC I: NSLS Superconducting Wiggler Magnet Cryogenic System

H. Hsieh presented an introduction on the purpose of the wiggler magnet in the NSLS program and an explanation of the use of shorter wavelengths of light as a non-invasive diagnostic tool for angina victims. The scheme, known as Life-Scan K-Edge Imaging System, is sponsored by the National Institute of Health and others. Demonstration photos of the scanning of a dog's heart and cardiac vessels were taken at SLAC. The NSLS at BNL is expected to provide superior scanning due to the brighter source and better collimation.

Hsieh also provided a description of the wiggler magnet (6-pole, no return yoke, 6 Tesla field) and its cryostat.

M. Iarocci presented details of the refrigerator, piping, controls and safety systems. The refrigerator is a CTR Model 1430 with which BNL is familiar. There will be 5600 gal. of liquid nitrogen storage. the system will use a microprocessor for control and data-logging.

Continued----->

CSC Minutes (12/11/86) continued:

The magnet is designed for 6 Tesla field, and will be powered to 5 T to obtain the desired wavelengths. The stored energy at 5 T is calculated to be 0.5 M Joule. Quench testing at 6 T created a ΔP in the magnet cryostat system of 18 psig. The ΔP at 5 T is estimated to be approximately 15 psig. The storage dewar is pressure-regulated at 2.5 psig and this value is increased to 3-4 psig during a test quench. The primary pressure relief valve is set at 10 psig, the secondary valve at 30 psig, and the burst disc rated at 35 psig. The magnet cryostat holds 52 L of LHe.

A description of the system alarms, interlocks and quench protection followed. The Committee recommended that an automatic valve be installed in the system to open upon a quench and relieve the increased pressure back into the refrigerator system before the relief valve(s) open.

A maximum of 1456 cu.ft. in free volume of helium gas could be released within the building. The Committee was not overly concerned about this amount in the volume of the building. The refrigerator building will not be connected to the main building HVAC system. There will be oxygen deficiency detectors and automatic exhaust fans.

The reason for the warm (room temperature) bore tube was explained. The heat load is estimated at 1 W.

The refrigerator has been undergoing testing. Magnetic measurements on the magnet are in progress. Installation in the planned location will begin soon. The full test is scheduled for the summer of 1987.

A. Prodell raised a question on the possibility of a collapse of the copper tube in the field. The Committee requested that the NSLS engineers address this question.

A motion was made by R. Young, seconded by R. Gibbs to approve the NSLS proposal. Approved 5-0.

TOPIC II: HFBR Liquid Nitrogen Storage Facility

V. Lettieri presented a proposal for the purchase and installation of two 6000 gallon liquid nitrogen storage vessels at the Cold Neutron Facility of Building 750 (High Flux Beam Reactor). The tanks are to be built by Process Engineering Inc. to all applicable codes and standards.

A review of the specifications caused the Committee to question the specified inner vessel relief valve setting of 70 psig and burst disc rating of 105 psig for a vessel with a maximum allowable working pressure of 70 psig. The HFBR is going to change the specifications.

Continued----->

CSC Minutes (12/11/86) continued:

The Committee also noted that the piping test pressure is specified as only 90% of the vessel test pressure. The specification will be changed to make both pressures the same.

The Committee also advised that all test pressures for the LN₂ vessel should be specified as differential pressures, not gauge pressures, due to the vacuum insulating jacket. The test should reflect the ΔP that the vessel will experience with the jacket evacuated.

A review of the drawings elicited a request by the Committee to combine the drawings into one. With all the piping and valves shown on one drawing, it would be easier to visualize the system and check against any possible trapped volumes of liquid nitrogen.

The manufacturer's Evaporation Rate Test Procedure was reviewed. A clarification on the location of the thermometers was requested.

The HFBR is to provide copies of their Operating Procedures to the Committee for review.

A motion was made by R. Gibbs, seconded by R. Young to approve the HFBR proposal, subject to the specification changes cited above. Motion passed 5-0.

Meeting adjourned at 3:20 P.M

Respectfully submitted,

Frank J. Thornhill
Recording Secretary

Distribution:

Cryogenic Safety Committee Members

Others Present

C.W. Flood, Jr.

G. Kinne

C. Meinhold

CSC Recommendations Approved:

G. Kinne, Associate Director