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**SUPERCONDUCTING X-RAY LITHOGRAPHY SOURCE PHASE I (XLS)
SAFETY ANALYSIS REPORT**

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Editor: L. Blumberg

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NATIONAL SYNCHROTRON LIGHT SOURCE

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**Superconducting X-Ray Lithography Source
Phase I (XLS) Safety Analysis Report**

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1. Introduction and Description of the Facility

The XLS facility comprises a small 8.5 m circumference race track-shaped electron synchrotron operating at 200 MeV energy or lower, and a spur beam transport line taken off the existing x-ray ring injection transport line. The synchrotron will be housed in a concrete shielded enclosure situated inside of the x-ray ring near the injection point. Fig. 1 shows the position of the XLS Synchrotron in the NSLS building (the outlined rectangle), while Fig. 2 shows a detailed plan view of the facility.

The XLS (or Phase I) machine has room temperature dipoles operating at 1.2 Tesla, and will be the precursor or analogue of a superconducting x-ray lithography source (SXLS or Phase II) machine, which will use superconducting dipoles operating at 4 Tesla, and which will be the prototype of an industrially produced device. The Phase II machine will be the subject of a future SAR.

Phase I has as its goal the establishment and testing of the critical machine parameters for a compact synchrotron. Studies with the Phase I storage ring will form the basis to proceed with Phase II, a full prototype superconducting compact ring. Specifically, the XLS is an 8.5 m circumference storage ring with room temperature magnets to test lattice design, injection parameters, ion trapping effects and their correction, beam dynamics with simulated superconducting magnet fringe fields, current limiting instabilities and their correction, and to define a control system suitable for a synchrotron in an industrial environment.

2. Policy

2.1 Introduction

There is a strong commitment to safety at the NSLS as evidenced by the number of persons involved directly in the safety program. In addition to the Department Safety Coordinator, there is a Safety Officer, and an Assistant, both of whom are fully employed on safety issues. The Safety Area Representative for the area where the XLS will be located will have direct responsibility for bringing XLS safety issues to the Safety Coordinator as outlined in the attached memorandum (Attachment 2.1). The XLS Facility will be included in the regular NSLS Safety Tour program which covers each area at least every three months. Also there are nine Safety Operations Coordinators whose primary function is to ensure safe operation of the Experimental Beam Lines. A senior member of the Safety and Environmental Protection Division works in liaison with the Department on safety-related matters and two safety professionals of that Division are permanently assigned to the NSLS Department.

2.2 NSLS Safety Committee

The XLS program is administratively part of the NSLS Department and as such will be reviewed by the NSLS Safety Committee for both the operation of the accelerator and any possible experimental facilities. All areas of safety are considered by this committee which determines if proposed activities meet NSLS safety requirements and which advises NSLS management on safety policy. A current list of the NSLS Safety Committee membership is given in Attachment 2.2.

2.3 Laboratory Safety Committee

Whenever policy changes not covered by this document or requiring a new

FIG. 1(1) XLS AREA AT THE NSI

Fig. 2 (1)XLS RING IN BLDG. 725 NEAR X-RAY RING

SAR are made by the NSLS Department Safety Committee they are brought to the Laboratory Safety Committee for their review and recommendations. The policies are not implemented until such a review has taken place and approval from the Director's Office has been obtained. In addition to the Laboratory Safety Committee Reviews, members of the Safety and Environmental Protection Division act as advisors to the Department in any safety matters. The Safety and Environmental Protection Division Representative assists the Department in the implementation of the Laboratory Safety Program and also assists in training NSLS personnel in safety matters.

2.4 Safety Training

For many of the training areas such as, for example, respiratory training, safe crane operation, materials handling and film badge usage, the training will be given through regularly scheduled Safety and Environmental Protection Division Programs. However, there are a number of topics related to the XLS which will require separate training programs. Topics such as electrical and radiation safety will require such training. For example, written procedures for securing radiation areas and for the operation of high voltage equipment will be provided and the staff will be trained to carry out these procedures.

3. Building Systems

3.1 Introduction

The x-ray lithography source (XLS) Phase I storage ring will be housed in a concrete vault in Building 725 in an area adjacent to the x-ray storage ring tunnel. This location takes advantage of injection to the XLS from the existing Booster Synchrotron. To accomplish this, a new concrete shield wall has been constructed as shown in Fig.1 (3.3), and an opening made in the existing shield tunnel wall for the beam transport. Normal access to the shielded room is through a door at the east end of the enclosure. There are two doors from the room into the x-ray storage ring tunnel. The maximum travel distance from any point in this shielded area to the egress door is 30 feet.

Deionized water will be provided from the existing NSLS system. About 32 gpm of 74°F water is required. Compressed air at 90 psi will also be piped from an existing system. Electrical power is taken from unit substation No. 1 to a 1600 amp bus in the new RF extension and then to two 400 A, 480 V panel boards.

The control room is located in a trailer in the building courtyard quite close to the XLS as shown in Fig. 1 (1). The trailer is powered from the existing building and will contain smoke detectors and portable fire extinguishers. Sprinklers will also be installed since the trailer is less than 25 feet from the x-ray experimental building (see attached memo #3.4.4: J. Levesque to C. Weilandics, July 14th, 1989).

3.2 Building Services

3.2.1. Water Systems

Water from the existing NSLS closed-loop system will provide for the cooling of magnetic components, beam chamber and of power supplies. Water

will be supplied by the High Pressure Copper System (HPC), and the Low Pressure Copper System (LPC) respectively. Each system utilizes a mixed-bed deionizer to produce water with a resistivity of approximately 5 meg Ω -cm, which is supplied to the loads at 74°F $\pm$.5°F and 120 psi Δ P (HPC), 90 psi Δ P (LPC). Approximately 20 gpm will be required for magnet and RF cooling and 12 gpm for power supplies. Taps will be made in the existing X-ray ring headers to conduct the water to/from the components via copper pipes.

3.2.2 Air System

Low pressure air (90 psi), required to operate the two VAT valves and seven flags on the vacuum chamber, will be supplied by the existing NSLS system.

3.2.3 Electrical Power Distribution

The Power for the XLS is taken from Unit Substation #1 through a 1600 Amp contactor (A3 location) to a 1600 Amp Main Bus located in the new RF extension. From this Bus two safety disconnect switches each capable of delivering 400 Amps at 480 Volts are used to power two 480 Volt panel boards (NEMA 1 type), one to be located on the wall of the RF test room, the other located near the XLS Power Supplies.

From one of these panel boards a 112.5 KVA Transformer is used to convert the 480 Volts to a 208/110 panel board (two) for use of all other power supplies and utilities. In addition, the interior of the XLS Shielded Cell will have a 208/110 panel board located inside for local ring and service needs. The trailer will have its own power thru a local 45 KVA Transformer. The block diagram for the electrical power distribution system is shown in Fig. 1 (3.2.3).

3.3 Enclosure Access and Egress

The normal access to and egress from the XLS enclosure, which has approximately the same floor space as one of the larger staff offices, is through the main door of the east end of the enclosure as shown in Fig. 1 (3.3). This door is also the main entrance to the x-ray ring (see description of security system below: 3.4.1 and 3.4.2). The line marked in Fig. 1 (3.3) illustrates this path. Machine components and personnel will use this path for normal entry and exit. Two other doors (marked Door 1 and Door 2) serve this enclosure; both open on the x-ray ring tunnel. Nowhere in the XLS enclosure is a person more than 30 feet from an exit to a corridor.

3.4 Hazards and Controls

3.4.1 X-Ray Tunnel Security System

The X-ray tunnel of the NSLS and the XLS machine area are subject to radiation, and a system for clearing all personnel and securing these areas has been implemented and is described below and in section 3.4.2.

Each system is made up of hard wired relay logic in a fail-safe configuration. Each interlock system undergoes a complete functional test after any work is done on the system, after any malfunction is reported, and at least every six months. The tests are recorded on individual check sheets, and are summarized in the Personnel Interlock Maintenance Log. The

Fig. 1(3.2.3) XLS Electrical Power Distribution System

Fig. 1 (3.3) XLS Ring in Building 725 Near X-Ray Ring

interlock testing and test records are under the supervision of the NSLS Safety Officer.

Tunnel Search Procedure

The existing search procedure for the x-ray tunnel is described in the memorandum in attachment #3.4.1. Minor changes to the previous procedure were required to accommodate the second entrance door added on the other side of the XLS injection line. A second "search start" button is provided by the second entrance, and both buttons must be pressed simultaneously to initiate the search. At the end of the search, both buttons must be pressed simultaneously to provide the ten-second interval when the doors may be opened for exit. This insures that the two searchers are in the proper positions when starting the search and exiting the tunnel.

3.4.2 XLS Area Security System

Due to possible radiation hazards that may exist in the area of the XLS synchrotron, any entrance to this area will be prohibited unless certain safeguards are in place. While any synchrotron radiation is confined to the inside of the XLS machine by the beampipe, bremsstrahlung radiation may exist due to stored beam in the ring and also due to the injected beam coming from the booster. The machine components are enclosed inside of a concrete block shielding wall with one access door and two doors to the x-ray tunnel. A hardwired interlock system consisting of electromechanical switches and relays with failsafe features is used. Redundant circuits are employed for personnel protection in case of a breach of the security system, intentional or accidental.

When it is desired to operate the machine, the XLS operator must operate two check stations sequentially, which forces him/her to make a complete tour of the area. After activating both stations, the operator has 30 seconds to leave the area, close the door and press the exit check station. Failure to complete the search in the specified time will nullify the search and it must be repeated. The door is locked, releasing the key which may then be returned to its SRU (Solenoid Release Unit) and rotated. This allows the machine to be returned to operation, i.e., the injection magnet power supply can be turned on and the shutter opened at the operator's discretion.

There are two modes to the security system; one mode is the everyday working access to the area, and the other is the "fault condition" or unauthorized entry.

In order to gain access to the XLS area, the Area Door Kirk key must be rotated and removed from its SRU. This key can only be removed if the XLS beam stop shown in Fig. 1 (3.3) is closed, the injection bending magnet power supply is turned off, and the Booster-to-X-Ray beam stop, shown in Fig. 2(1), is closed. Once rotated in the SRU this interlocks the XLS and X-Ray injection beam stops so that they cannot be opened and also interlocks the bending magnet power supply from being turned on. This key is then used to unlock the area door. It is held captive in the door lock until the door is again closed and locked. Personnel can now enter and exit the area in normal fashion.

The additional requirement for a hard wire interlock on the X-Ray injection beam stop, noted above and further discussed under Radiation Hazards Section 4.3.1.1, was necessitated by the outcome of radiation studies

summarized in Attachment 4.3.1-2 which indicate excessive radiation levels in the XLS cave during both normal and fault conditions of X-Ray ring injection. Thus, injection to the X-Ray ring will be possible only when the XLS cave is secured.

In the event that access to the area is attempted without going thru the above procedure, the redundant door switch circuits signal a fault condition, and the following actions take place:

1. Linac RF system is turned off.
2. Injection bending magnet power supply is turned off.
3. XLS beam stop is closed.
4. XLS dipole magnet power supply is turned off.
5. XLS ring RF is turned off.
6. Booster-to-X-Ray injection line beam stop is closed.

In addition to the above, a separate kirk key is provided which allows the safety officer to "lock out" the system when the XLS is not operational due to removal of shielding or other safety factors. The required search procedure to secure the XLS area is detailed in the attached memorandum #3.4.2.

3.4.3 Occupational Health Hazards

The occupational health hazards associated with building systems have been dealt with in the NSLS SAR 7/82 and the NSLS Phase II SAR 6/89.

3.4.4 Fire Hazard and Control

The XLS shielding enclosure is located within the existing NSLS facility, in the vicinity of the RF power supplies. Therefore, the area has all the automatic and manual fire protection that the NSLS building has, as described in the July 1982 Safety Analysis Report. Consequently our only concern is with the new enclosure itself and the trailer housing the control room. Since the accelerator is built of non-combustible materials and because of the shielding enclosure's non-combustible construction, consisting of solid concrete block walls, a concrete floor and a partial roof consisting of solid concrete blocks supported on a steel roof deck, and the remainder of the roof relying on the 18" thick reinforced concrete ramp above for roof shielding, the expected incidence of a fire starting and spreading is extremely small. The only sources of combustion are the wiring and cabling. Should a fire originate, the release of radiation or toxic chemicals to the environment would be inconsequential.

Approximately 6 existing pre-action sprinkler heads are at the XLS enclosure location. These heads are to remain and will provide the basis for fire protection within the enclosure. The pre-action system is in accordance with NFPA 13, Ordinary Hazard, Group II and is activated by smoke detectors (alternating photo-electric and ionization type) which are designed to comply with NFPA 72E. A portable Halon fire extinguisher, similar to others used in the building, will be located within the space in addition. The XLS power supply racks, located outside of the shielding enclosure, will also be protected by this same pre-action fire zone and the existing sprinkler heads in their vicinity.

The shielded enclosure will have an exit sign to direct traffic out of the enclosure and battery-powered emergency lighting. The means of egress from the XLS area is through a five foot wide archway leading to a five foot door opening. Egress from the x-ray tunnel is either through a three foot door or a pair of doors leading into the XLS area and then exiting as described above. In all instances, the exit access through which someone must pass to reach the exit discharge point is at least three feet wide. All doors are hinged and swing in the direction of egress and can be opened with less than 30 pounds of force.

The control room is located in a 12 foot wide by 55 foot long trailer. The trailer is in the building courtyard adjacent to the RF Area shown in Fig. 1-1 and quite close to the XLS, and will contain a portable Halon fire extinguisher, smoke detectors and sprinklers as recommended in the attached memo (#3.4.4). Five equally spaced sprinkler heads in the trailer are on an extension of the pre-action sprinkler system that serves the RF Area.

The total value of the equipment located within the shielding is \$2,500,000. This amount is well within the dollar value limits of \$25,000,000 above which we would be required to install redundant fire protection equipment as specified by DOE 6430.1A (General Design Criteria Manual), DOE 5480.7 on Fire Protection and DOE/EP-0108 (Standard for Fire Protection of DOE Electronic Computer/Data Processing System).

In the event of a total loss of the facility in a maximum credible loss, programmatic impact is less than six months.

4. Storage Ring Systems

4.1 Introduction

The XLS comprises a beam transport system from the x-ray injection line to the ring, and a storage ring. The transport line consists of dipole bending magnets and five quadrupole magnets for shaping and focusing the beam. The storage ring consist of two 180° bending dipoles, four quadrupoles and four sextupoles, injection hardware and RF cavity. In addition, both systems contain various diagnostic components for beam position, current and shape monitoring and steering magnets for beam position correction. The power supplies and controls for the magnets and RF cavity are located in two racks outside of the shielding enclosure. Operations personnel will be in a separate control room approximately 100 ft. away from the XLS ring.

The transport line and ring will be shielded with lead and concrete of sufficient thickness to allow normal occupancy of the adjacent areas of Building 725. The area surrounding the XLS enclosure is a controlled area but not a radiation area.

4.2 Storage Ring Operations

The XLS will have one primary operating mode, injection and storage of 200 MeV electron bunches from the booster. Injection at lower energies is also contemplated; however, 200 MeV operation will be the primary function.

The injector for the XLS is the NSLS booster synchrotron. Its repetition rate is 0.667 Hz (or 40 shots/min), and its output energy is determined by truncating the magnet ramp. For XLS operation it will produce $\approx 4 \times 10^9$ electrons in a single bunch at a maximum energy of 200 MeV (the XLS injection

line is designed only for 200 MeV energy operation and below; thus full energy electrons [750 MeV] which the booster produces for x-ray ring injection can not be diverted into the XLS enclosure). The electrons are then injected into the synchrotron in a more or less lossy fashion. The projected current stored in the XLS is 200 mA or 3.5×10^{10} electrons. For the initial commissioning of the machine we assume each fill will take 20 minutes (i.e. 3.2×10^{12} electrons from the booster). We limit fills to 200 per month. A control document in the form of the attached memorandum #4.2 has been provided to the operations staff which will limit the fills to the above stated conditions, as is presently done for the VUV ring. The shielding calculations must account for these losses. As the experience with the machine increases, the fill times will become shorter and the ionizing radiation produced by the facility will decrease. A heavy metal beam stop for personnel protection will be installed between the two bending magnets in the transport line (see Fig. 2-1); scattered radiation from this device must be shielded.

During injection, electrons will be lost in the transport line and circumferentially around the XLS. However, most losses will occur at the injection septum based on our experience with the two existing NSLS storage rings. Ultimately, all electrons injected into the XLS enclosure will be lost there, whether they are missteered or injected efficiently into the ring, and the shielding must be designed appropriately.

Access to the XLS enclosure is required during regular operations of the x-ray ring. Sufficient shielding between the x-ray ring and the XLS enclosure must be provided to allow this. However, recent radiation studies (Attachment 4.3.1-1) indicate that the existing shielding of the XLS enclosure is inadequate during X-Ray ring injection, and we will therefore exclude personnel from the enclosure by means of hard wired interlocks until such time that additional shielding is in place (see additional remarks in Sections 3.4.2 and 4.3.1.1). Security systems to prevent diverting electrons into the XLS enclosure during x-ray ring injection are provided as described in Section 3.4.2.

4.3.1 Radiation Hazards

4.3.1.1 Prompt Radiation Hazards

In principle, any point along a beam line is a potential radiation source. However, we can identify several points as significant prompt hazards in normal 200 MeV XLS operation from knowledge of the beam optics and the expected operating modes. Several potential hazards which could result from error conditions can also be identified. For purposes of this report we will discuss normal operations and accident situations separately, and further subdivide operational modes into Storage, Injection and Maintenance.

4.3.1.1.1 Normal Operation

(1) Injection Mode

We expect that the injection process will present the largest losses, and thus the most significant prompt radiation hazards during normal operations. During the initial commissioning phase and before optimal magnet settings have been established we have assumed extremely inefficient injection for purposes of shielding calculations. We assume that the present maximum bunch intensity from the Booster, 4×10^9 electrons, will be injected

into the XLS at the present maximum Booster cycling rate of 40 bunches per minute, and that the injection process to fill the XLS ring to the desired maximum intensity of 200 mA (3.5×10^{10} electrons) will require 20 minutes. Thus, we assume that 99% of the injected beams will be lost! For model calculations we assume that the losses are distributed on known apertures in the transport line and storage ring as stated in the shielding section, 4.3.2.3. The dominant loss point, 40%, is the injection septum. The shielding calculations discussed in Section 4.3.2.6 for this normal injection mode are summarized in Figs. 6(4.3.2) and 7(4.3.2) of that section; in particular, Fig. 6(4.3.2) shows that the dose rate outside of the end wall is generally less than 2.5 mrem in an hour except for a small area in the forward direction relative to the injection septum where the rate attains 6.5 mrem in an hour. As noted in that section, the calculated rates will be reduced by a factor of approximately two when proper account is taken of the slant thickness of the bending magnet steel return yoke. In addition, the 1" lead belt, shown in Fig. 2(1) and discussed further in Section 4.3.1.1.2 reduces these normal operation values by an additional factor of 3.2. (The lead belt was added after the calculations for Figs. 6(4.3.2) and 7(4.3.2) were made.) Thus, the resultant peak rate is below the 5 mrem in an hour limit for radiation workers in this controlled area. Similarly, the peak dose rate outside the side wall of the XLS cave, given in Fig. 7(4.3.2) and resulting from the assumed 20% loss in the bending magnet downstream of the injection septum, is no more than 2 mrem in an hour.

Other areas of concern have been similarly addressed in Section 4.3.2.6 including the uncontrolled and generally unoccupied area above the 18" concrete ramp which serves as the roof of the XLS cave and for which a peak rate of 3.6 mrem/hr (neutrons plus bremsstrahlung) has been calculated. Attention has also been directed at the problem of the uncontrolled and generally occupied office space above the entrance maze, and an additional 8" concrete roof has been added to reduce the integrated dose in the offices below the 100 mrem/yr limit required. In general, during the start-up phase of the XLS operation, access to the area adjacent to the facility will be controlled while NSLS and local S&EP representatives carry out radiation studies to determine regions giving rise to radiation sources under both normal and fault conditions. Any loss points thereby identified will be locally shielded to alleviate the burden on general shielding.

(2) Normal Storage Mode

The XLS will be filled to an initial beam current of 200 mA (3.54×10^{10} electrons) with an estimated initial beam lifetime ($1/e$) of 20 minutes. Since the beam lifetime increases as the current decreases, we expect a useful storage lifetime of about one hour, after which the remaining beam will be dumped by turning off the RF. The dumped beam will target on the injection septum which will also be the loss point for the slow losses during the storage period. These losses are only 2.8% of the hourly injection losses discussed above, and therefore present a negligible hazard compared to injection.

(3) Normal Maintenance Mode

Access into the XLS cave is desired for normal maintenance during periods when the X-Ray ring is operating in either its storage mode (2.5 GeV) or injection mode (750 MeV). Clearly the X-Ray injection mode is the more serious prompt hazard since the injection line, shown in Fig. 2(1), is adjacent to the XLS cave and since the X-Ray ring now has a stored beam lifetime of about 20 hours but is fully charged with 750 MeV electrons to

about 200 mA in approximately 10-15 minutes. Radiation studies conducted by NSLS and S&EP staff and included here as Attachment 4.3.1, confirm these expectations; the normal losses from the X-Ray ring storage mode contribute only 0.7 mrem/hr inside the XLS cave at entry door #1 [Fig. 2 (1)] whereas "normal" 750 MeV injection to the X-Ray ring resulted in levels of 28.5 mrem/hr at the same location. This high level is attributed to beam hitting injection line Flag #3, indicated in Fig. 2(1), even with the flag in its nominal "out" position. We thus face the choice of either shielding the X-Ray injection line adequately for both these "normal" operation losses and the fault conditions discussed in the following section, or clearing the XLS during X-Ray injection. Simply modifying Flag #3 so that it is fully extracted in its "out" position will not solve the problem since this flag is an important diagnostic and should be capable of being inserted during X-Ray injection. We, therefore, choose at this point to clear the XLS cave during X-Ray injection until such time that adequate shielding can be installed.

Written procedures for exclusion of personnel from the XLS cave during X-Ray injection are included as Attachment 4.3.1-3 and document the operational procedure which has already been implemented since the results of the studies report became known. The written procedure, furthermore, serves to inform the operations group of the safety requirements. The basic safety system to insure that the XLS cave is secured during X-Ray injection is the hard wire interlock to the Booster-to-X-Ray beam stop as noted in Section 3.4.2.

Other recommendations from the studies report such as installation of radiation signs and a chipmunk radiation detector has been implemented. The high radiation levels measured during beam mis-steering will be discussed under fault conditions in the following section.

4.3.1.1.2 Accident Situations

(1) Injection Mode Fault Conditions

As in the normal operating mode, injection presents the most serious radiation hazard in a fault condition in terms of the total number of electrons lost per hour, since we assume that all electrons injected from the Booster can be lost in the 20 minute injection interval. Unlike the normal operation, however, an accident could target the injected beam at unexpected locations within the injection line-ring system. In general, any point within the system is a potential loss point due to beam mis-steering or magnet power supply failure. We, therefore, opt for installing a lead belt completely around the XLS ring, as shown in Fig. 2(1). The thickness of this belt is taken to be 1" which produces a factor of 3.2 attenuation in bremsstrahlung intensity using the 25 gm/cm² attenuation length quoted in Table 1, Section 4.3.2.4. This thickness is sufficient to reduce the peak shown in Fig. 6 (4.3.2) at $x' = 0$ due to a 40% loss of injected beam at the injection septum to 5 mrem/hr for 100% loss. Similarly, the 1.5 mrem/hr peak shown at $x' = 3.5$ m in Fig. 6 (4.3.2) resulting from an assumed 5% loss in the injection line within the XLS cave and upstream of the septum will present no problem if credit is taken for the belt thickness on both sides of the XLS ring and for the slant angle through the lead and steel return yoke of the 180° bend magnet. An additional one inch of lead has been added [see Fig. 2(1)] on the inner side of the injection septum to provide needed additional attenuation in the event of failure of that component during injection. (Note that Fig. 6 (4.3.2) and 7(4.3.2) are calculated without the lead belt). The 5 mrem/hr peak level shown in Fig. 7(4.3.2) outside the 24" side wall ($x = 3.8$ m) resulting from an assumed 20% loss around the 180° bend

will also be adequately reduced by the lead belt for a 100% loss if a credit of 1.5 in slant length is taken for the belt thickness.

The levels above the 18" concrete ramp which constitutes the roof of the XLS cave will also be less than 5 mrem/hr when 100% loss occurs in the cave since, in Section 4.3.2.6, the roof level is 3.6 mrem/hr with 80% total loss in the cave. Similarly, the annual dose in the office area adjacent to the 18" ramp and above the entrance maze will remain under 100 mrem/yr when the bremsstrahlung rate of 300 mrem/hr in the maze area is attenuated by the lead belt. Also, note that no credit is taken for the obvious fact that the fault condition will not be present for a significant fraction of the total operating time within a year.

For the upstream end of the XLS injection line in the alcove created within the X-Ray ring tunnel, shown in Fig. 2(1), a loss of 20% was assumed for normal operation. However, a 100% loss situation for 10^{13} electrons was considered in the shielding calculations of Section 4.3.2.5 for the beam stop between bending magnets BXLSB1 and BXLSB2 and it was found necessary to add 2" of lead and 4" of concrete above the beam stop, in addition to an 8" concrete roof over the alcove, to provide adequate protection above the alcove - an area not under the 18" concrete ramp. If we have a 100% loss within the bending magnets, the vertical shielding will be provided by the 7.8 cm steel yoke of the magnet.

Although the steel provides a bremsstrahlung attenuation factor of only 5.25 whereas the lead plus concrete (assumed density 2.3 gm/cm³) provides a factor of 17.50, the missing factor of approximately 3 can be provided either by noting that the beam stop calculations were for a 10^{12} electron loss whereas the 100%, 20 minute electron loss is 3.2×10^{12} , or by placement of a 1" lead sheet on top of the dipoles should measurements prove this to be necessary. It should be pointed out that the region above the alcove roof is in line of sight to the roof of the X-Ray experimental building and, as noted in Section 4.3.2.2, the roof area can be posted and barricaded to permit radiation levels up to 100 mrem/hr. For forward shielding of a 100% dump within the dipoles, we can take credit for the slant angle through the 7.8 cm steel yoke as well as the lead and concrete already in place adjacent to dipole BXLSB2 as required for the beam stop shielding. Finally, we have considered a worst case injection accident whereby the full energy 750 MeV beam to the X-Ray ring is partially bent into the XLS injection channel if magnet BXLSB1 is energized. K. Batchelor (see attachment 4.3.1.1.2) has performed shielding calculations for this case and concluded that a lead shield of 24-inch thickness in the crotch between BXLSB1 and the X-Ray injection line [see Fig. 2(1)] will adequately attenuate the 750 MeV cascade. Subsequent measurements on April 25, 1990 by the NSLS and S&EP staff with the above recommended lead thickness (see attachments 4.3.1.1.2-1, 2, and 3) confirm that the radiation levels in the forward direction and outside the XLS shield wall will be less than 5 mrem in an hour. The measured levels of 28 mrem/hour at detector #10, located above the tunnel roof and noted in attachment 4.3.1.1.2-3, resulted from the absence of the 12-inch concrete shield above the lead recommended by Batchelor. The final shielding will include the concrete. Also note in Fig. 2(1) that a 4-inch lead plus 8-inch concrete side shield has been added on the south side of the X-Ray injection line to protect the X-Ray experimental floor.

(2) Storage Mode Faults

As previously noted, the stored beam of 3.5×10^{10} electrons is only 1% of the assumed injected beam, and under normal conditions we are already assuming that 75% of the injected beam will be lost within the XLS ring.

Thus, a fault condition during the storage mode will present no new hazards that have not already been taken into account under injection faults.

(3) Maintenance Mode Faults

The Radiation Studies report in Appendix 4.3.1 also considered a fault condition - missteering of the 750 MeV booster beam during X-Ray ring injection. Levels of 110 mrem/hr were found within the XLS cave adjacent to the borated polyethylene door #1. Thus, even if we were to modify or interlock Flag #3, which appears to contribute to these high levels, it seems unlikely that this action alone would reduce the levels to less than 5 mrem/hr. There are only two options available - shield the X-Ray injection line adequately or exclude personnel from the XLS cave during X-Ray ring injection. We elect to clear the XLS cave during X-Ray injection; the written procedures describing interlocks as noted in Section 3.4.2 are given in attachment 4.3.1-3. It should be noted that the studies report also presented data to show that the XLS cave levels are adequately low during either a 750 MeV or 2.5 GeV dump of the X-Ray ring beam. We regard the possibility of beam entering the XLS cave during a maintenance mode as life-threatening and have therefore provided a beam stop, shown in Fig. 2(1) and discussed in Section 4.3.2.5, as a redundant device to prevent such a situation in the unlikely event that personnel are still in the cave during X-Ray ring injection and a failure of the interlocks on the X-Ray injection beam stop and the power supply for XLS injection dipoles BXLSB1 and BXLSB2 has occurred.

4.3.1.2 Activation Hazards

Beam losses described in the preceeding section will activate both machine components (vacuum chamber, magnet yokes and beam dumps) as well as the surrounding lead shielding and air, principally via photoneutron reactions. During normal operation the principal losses are expected during injection and occur both in the injection line and the XLS ring as described and quantified in section 4.3.2. The expected loss regions are locally shielded for prompt radiation, and that shielding will also serve as protection from residual activity. Experience with similar losses, viz. momentum slits, injection system, etc. on NSLS components justifies these shielding expectaions.

In normal operation the beam path is entirely within vacuum; therefore, the cascade resulting from electron losses is initiated by interactions at nearly grazing incidence at the periphery of the vacuum chamber - generally nonelastic electron scattering events accompanied by bremsstrahlung. The scattered electrons and gammas will then either exit from the vacuum chamber and interact within the external lead shielding abutting the chamber which is sized to contain the cascade or, with essentially equal probability, reenter the vacuum chamber and interact at some downstream point on the wall.

The situation with regard to accidental losses is similar except that, with component failure, we can expect the beam to impact the vacuum chamber at large angles relative to the surface and interact principally within the external lead shield. Thus, assuming that the loss points have been properly identified in section 4.3.1.1, it seems reasonable to assume that no more than 50% of the electron loss will lead to cascades in the surrounding air.

The activation problem in air has been discussed by K. Batchelor (SAR for the BNL-ATF, 1989). He identifies ^{13}N (10 min., β^+) and ^{15}O (2 min., β^+) as

the principal hazards and based on the formulation of W.P. Swanson (IAEA, Vienna, 1979, Technical Report Series #188), he estimates the saturation activities of these nuclides as $5.6 \mu\text{Ci}$ and $0.6 \mu\text{Ci}$ respectively from the ATF at 50 MeV and beam power of 8 watts. We can scale from these results by noting first that the XLS beam at 200 MeV, 4×10^9 electrons/pulse, 40 pulses/minute has a beam power of only 0.085 watts. If we further consider that all of the XLS losses will be initiated by electrons of > 10 MeV, whereas K. Batchelor estimates that only 5% of the ATF electrons will be above that energy, and further note that only about 50% of the XLS electrons could generate air activation, then we obtain saturation activities about a factor of ten smaller than the quoted ATF values. If we assume that the activity is uniformly distributed in the XLS vault, which has about 1/4 the volume of the ATF enclosure, the resulting average activity densities are $6.2 \times 10^{-9} \mu\text{Ci/cm}^3$ and $6.6 \times 10^{-10} \mu\text{Ci/cm}^3$ for ^{13}N and ^{15}O respectively - less than 1/2 the ATF values and well below the quoted MPC tolerance level of $2 \times 10^{-6} \mu\text{Ci/cm}^3$.

It should be pointed out that part of the XLS injection line is within the x-ray ring tunnel enclosure, so that air activation from losses in the upstream end of the injection line will be vented by the existing ring ventilation system. However, the XLS vault is not force-ventilated; activity produced near the XLS ring will diffuse over the top of the 11-foot shielding wall into the adjacent RF area which is ventilated.

Additional Environmental Protection Agency requirements on dose levels of airborne emissions at the site boundary, as noted in the attached memorandum #1 (4.3.1.2) (Miltenerberger to Heese, September 29, 1989), indicated the possible need of a NESHAPs application and evaluation. However, it was pointed out in the attachment #2 (4.3.1.2) (memo, Heese to Miltenerberger, September 29, 1989) that the XLS does not constitute a new source of emissions at the NSLS facility. A subsequent memo, attachment #3 (4.3.1.2) (Miltenerberger to Heese, October 11, 1989) submitted to the EPA along with additional documentation, concurs with the conclusion that the XLS Phase I facility does not require submission of a NESHAPs application. The above notwithstanding, we can show by scaling the yearly production of N^{13} and O^{15} within the XLS vault to the corresponding emissions from the ATF that the XLS is in compliance with present EPA standards of less than 10 mrem per year for maximum dose due to air emissions at the site boundary. The volume of the XLS vault is approximately 98.7m^3 which leads to $.612\mu\text{Ci/fill}$ for N^{13} and $.065\mu\text{Ci/fill}$ of O^{15} . At 2400 fills per year (200 per month) the total amount of these activities is 1.47mCi N^{13} and $.16\text{mCi}$ of O^{15} per year. Scaling to the 28mCi of N^{13} and 15mCi of O^{15} per year used in the NESHAPs application for the ATF we find $7 \times 10^{-5}\text{mrem}$ for N^{13} and $2 \times 10^{-8}\text{mrem}$ for O^{15} at the site boundary resulting from XLS emissions. These doses are negligible.

4.3.2 Accelerator Shielding

4.3.2.1 Introduction

This section will consider shielding for the X-ray Lithography Synchrotron being built at the NSLS Building 725. As shown in Fig. 1 (4.3.2) it will be placed next to the existing x-ray ring under the ramp leading to the interior of the building. The entryway is located under offices and the injection line and beam stop is under the roof which is readily accessible from the ramp.

Fig. 1^(4.3.2) XLS RING IN BLDG. 725 NEAR X-RAY RING

4.3.2.2 Design Criteria

The facility design and construction should be consistent with the DOE Order 5480.11 of 12/21/88 and DOE Order 6430.1A of 4/6/89. Thus the uncontrolled and generally unoccupied spaces such as the ramp above the facility and the generally unoccupied workspace adjacent to the facility shall have a radiation level under 5 mrem in an hour. The radiation received in these spaces by a radiation worker should be under 1 rem/yr and by a member of the public under 25 mrem/yr. The office spaces above the entrance maze should also have dose rates less than 0.5 mrem in an hour, but because the office occupant is not necessarily a radiation worker, the annual dose during normal working hours shall be less than 100 mrem, the national standard for exposure to non radiation workers. The facility roof should have levels under 5 mrem/hr unless posted and barricaded in which case the levels may be as high as 100 mrem/hr.

4.3.2.3 Loss Assumptions

The XLS will receive electrons from the Booster Synchrotron at 200 MeV and not accelerate them. The XLS with circumference of 8.5 m will store about 3.6×10^{10} electrons at the rated current of 200 mA. The injector is the NSLS Booster operating in the single bunch mode which can generate about 4×10^9 electron/pulse at 40 pulses/min or 1×10^{13} e/hour. We assume that 0.2 of the injected electrons are lost on the injection line upstream of the wall between XLS and the x-ray ring, 0.05 on the injection line between the wall and the ring, 0.4 on the injection straight section of the ring, 0.2 on the dipole downstream of the injection septum, 0.05 on the RF straight, and 0.1 on the other dipole. We require that a fill will occur within 20 minutes, that only one fill will occur in an hour, and that no more than 200 fills will be used per month. Loss of stored beam is irrelevant because the energy is the same and the assumed injected charge is 90 times the stored charge.

During construction, operation of the nearby x-ray ring will continue. Borated polyethylene doors will be installed between the x-ray ring and the XLS facility to provide neutron shielding and preclude access to the x-ray ring. Lead placed near the transport line and the x-ray ring will provide bremsstrahlung shielding. Filling this ring uses 750 MeV electrons from the Booster after which the 300 mA (1×10^{12} electrons) beam is accelerated to 2.5 GeV and then slowly decays over about 10 hours and is dumped. We assume the ring loss pattern has 0.02 of the lost electrons in each of the sixteen dipoles, 0.02 in each of the eight long straights, and 0.06 in each of the eight short straights and that the losses are uniform in these regions. During injection we assume that 0.2 of the loss from the booster to the stored ring current occurs on the transport line in the x-ray ring, 0.4 is distributed over the ring, and that 0.4 is a point loss near the injection septum (out of view from the XLS facility). With single-bunch booster operation, the maximum injected charge in one hour is only 10 times the stored charge. Injection will usually occur only about every 10 hours. Because of the time structure of x-ray ring operation and the low expected occupancy the hourly dose will be most restrictive.

4.3.2.4 Calculational Method and Radiation Source Terms

The high energy electrons lost will generate an electromagnetic cascade of bremsstrahlung, associated positrons, and electrons. The photons will in turn generate giant resonance neutrons (E_{av} about 2 MeV, $E < 25$ MeV),

intermediate energy neutrons (25-100 MeV), and high energy neutrons (above 100 MeV). For a point loss we calculate the dose equivalent for one type of radiation as

$$H_{ij} = N_j S_i e^{-d_j/t_i} / r_j^2 \quad (1)$$

where H is the dose equivalent, N is the number of electrons lost, S is the source term, d is the slant distance through the shield, t is the attenuation length for the radiation in the shield material and r is the distance from the loss point to the calculation point. Table 1 lists the radiation attenuation lengths t_i used for the different materials. Each material in a sandwich shield will involve an exponential attenuation term. The radiation field at any point is the sum of the field from the losses at all points and all types. The source terms S_i (rem m²/10¹⁵ e) are:

$$S_{gr} = 90 E \quad (2)$$

$$S_{gr} = R 10 E / (1 - 0.75 \cos(\theta)) \quad (3)$$

$$S_{ni} = R E / (1 - 0.72 \cos(\theta))^2 \quad (4)$$

$$S_{br} = (1,330,000 E e^{-\theta/0.834} + 133,000 e^{-\theta/0.159}) / 3000 \quad (5)$$

where E (GeV) is the electron energy and θ (radians) is the angle between the electron momentum and the dose point. The neutron source terms were developed at SLAC by Jenkins. The strength of the higher energy neutron terms are reduced by the factors R listed in Table 2 taken from Fig. 2 of the CERN report 84-2 and presented here as Fig. 2 (4.3.2). The bremsstrahlung formula Eq. 5 was parameterized by Swanson (ref) for the Aladdin upgrade with modifications to make it fit the 100 Sv m²/kW hr source term at 90° used for LEP (ref) and Monte Carlo calculations shown in Fig. 3 (4.3.2). An additional term due to scattered neutrons follows NCRP 79 and assumes a flux in the room of 5.4 Q/S where σ (m²) is the surface area of the room and Q is the total number of giant resonance neutrons generated. The scattered neutron energy is taken as 0.24 the initial energy and the dose equivalent is assumed to scale with E^{0.735}. Half the flux is heading toward the wall so

$$H_{ns} = 11.88 N S_{gr} e^{-d/t} / S \quad (6)$$

where N is the total number of electrons lost, d is the wall thickness, and t is the attenuation length for scattered neutrons.

Table 1: Radiation Attenuation Lengths (g/cm²)

	<u>Bremstrahlung</u>	<u>Giant Resonance Neutrons</u>	<u>Mid-Energy Neutrons</u>	<u>High-Energy Neutrons</u>	<u>Scatter Neutrons</u>
Iron	37	100	138	138	--
Lead	25	--	--	--	--
Concrete	42	30	55	120	20
Polyethylene	42	7	20	70	5

Table 2: Ratio R of Neutron Source Terms to High Energy Limit

<u>Electron Energy (GeV)</u>	<u>0.2</u>	<u>0.75</u>	<u>2.5</u>
Intermediate Energy	0.33	1.	1.
High Energy	0.016	0.35	0.8

Fig. 2(4.3.2) Effective source terms for a thick copper target for neutrons of energy 25-100 MeV and neutrons of energy greater than 100 MeV as a function of electron energy.

(4.3.2)
Fig. 3 Dose rates near a 1 cm diameter tungsten target struck by 200 MeV electrons as a function of angle. Target thicknesses used: 2, 4, and 10 X_0 .

4.3.2.5 X-Ray Ring Operation and XLS Beam Dump Issues

Installation of the XLS beam dump and injection line in the x-ray ring tunnel raises two issues for future operation which have been satisfactorily dealt with. The source terms are x-ray ring injection and 200 MeV beam on the XLS beam stop. Although the injection is at a higher energy, the loss is distributed so the net effect is reduced so that the XLS beam stop is dominant. It is also fortunately easier to calculate.

This stop will be shielded in the forward direction by 8" of lead or equivalent and 12" of normal concrete. The sides and top will be shielded with 2" of lead with 4" of concrete above the lead. An additional 8" of concrete will provide a roof enclosing the scattered neutrons. An elevation view of the XLS beamstop region and adjacent shielding is shown in Fig. 4 (4.3.2). The 4" borated polyethylene doors will provide additional shielding for the scattered neutrons and the nonlocal source from x-ray injection and the XLS transport line.

The radiation levels at both the roof and just behind the door as estimated with XLSSTP2.C are about 4 mrem/hr with 10^{13} 200 MeV electrons on the stop.

The x-ray doors also provide shielding for full operation of the Booster into the x-ray ring. The neutron radiation levels through 4" borated polyethylene doors are calculated to be 1.7 and 0.4 mrem/hr through door 1 and 2 respectively. Gamma dose at door 2 are calculated to be about 4.5 mrem/hr. Additional bremsstrahlung shielding of 2" lead will need to be placed along the x-ray injection line and 1" lead along the x-ray ring near door 1 to reduce the gamma levels to about 4 mrem/hr at door 1. Loss points known to be high can receive additional shielding to reduce levels further if necessary.

4.3.2.6 XLS Operation

The ring coordinate system shown in Fig. 5 (4.3.2) used the entry port of the bending magnet downstream of the injection straight as the origin with y-direction along the beam direction at that point and the x-direction directed away from the x-ray ring. The model of the XLS ring treated each bend as 20 sections and divided the straight sections into 0.2 m portions. The iron bending magnet has a 3 1/16" outer field return and a solid inner field return.

For modeling the dose rates through the 32" thick end wall, the shield was oriented at a 0.5 radian angle to the y-axis and the slant angle accounted for. The magnet steel was treated as a 62 gm/cm² shield normal to the radiation (beam is usually at a large slant angle) which intercepts all of the radiation. As shown in Fig. 6 (4.3.2) the dose rates along the wall are generally under 2.5 mrem/hr except for a small spot about 4 cm diameter immediately downstream of the injection straight section. The actual values will be lower by almost a factor of 2 because the iron shield is treated conservatively. There is a similar dose spike downstream of the injection straight.

For modeling the dose rates through the 24" side wall, the magnet steel was assumed to be effective for only the portion of the loss within the bends. The levels are primarily from the arc downstream of the injection point with the calculation having artifacts of the assumed stepwise bends.

SECTION A-A

Fig. 5 (4.3.2) XLS RING SHIELDING ASSUMPTIONS

FIG. 6 (4.3.2) END WALL DOSE RATES

The iron has been modeled as 62 gm/cm² normal to the radiation which results in levels shown in Fig. 7 (4.3.2) somewhat above 5 mrem/hr. The iron was also modeled as a more realistic 100 gm/cm² thickness dropping the levels to 3 mrem/hr near the wall for the assumed loss conditions. Part of the bend is obscured by the central field return, a condition not considered in the calculation. This portion of the facility is similar to a corridor for which an occupancy factor of 0.25 can be used. The average injected charge will be less than 1/3 of the maximum value so for 2400 fills the annual dose will be less than 1000 mrem.

The XLS operation will affect two areas overhead. The ring itself is under the 18" thick concrete ramp leading to the interior of the building. For the presumed operation, 3×10^{12} electrons are lost in the bends where the pole tips or copper coils attenuate the bremsstrahlung by a factor of 20. The total loss is treated as a point loss at 90° resulting in a neutron dose equivalent rate of 0.4 mrem/hr and bremsstrahlung rate of 3.2 mrem/hr.

The area above the entrance maze is an office which may have a non-radiation worker in it so the level there should be less than 100 mrem/yr. The calculated neutron dose rate unshielded by the concrete wall is 8.9 mrem/hr. Following Tesch the scattered radiation into the office is treated as the second leg of a maze with attenuation of:

$$\frac{e^{-r/0.45} + 0.022A^{1/3} e^{-r/2.35}}{1 + 0.022A^{1/3}} \quad (7)$$

where r (m) is the distance into the leg of the maze and A (m²) is the area of the maze. The maze area is poorly defined except at the door whose area of 3 m² is used. The net attenuation at $r = 3$ m is 0.0246 so the neutron dose rate is 525 mrem/yr. The bremsstrahlung dose rate in the maze is about 300 mrem/hr for which a reflection coefficient of 0.002 is applied. The door area is 3 m² so at 4 m the dose rate is 270 mrem/yr. This is attenuated by a 8" maze roof and a 2" concrete floor to under 100 mrem/yr. No credit is taken for the fact that some of the operation will be in off hours when the office is unoccupied.

4.3.2.7 Conclusions

The operating conditions upon which the shielding calculations are based can be summarized as follows:

- 4 x 10⁹ electrons/pulse from Booster
- 40 pulses/minute from Booster
- 20 minutes maximum XLS injection duration
- 200 MeV maximum stored beam energy
- 1 injection fill per hour
- 200 fills/month

Under these conditions, the side and roof shielding of the XLS cave are adequate to reduce radiation dose in adjacent controlled and uncontrolled areas to below tolerance levels except for a small (~4 cm diameter) spot in the forward direction relative to the XLS injection septum. Addition of a one-inch lead belt completely surrounding the XLS ring reduces this spike to below tolerance and also accommodates fault conditions which could produce in the worst case a 100% injected beam loss at any point in the ring.

FIG. 7 (4.3.2) SIDE WALL DOSE RATES

4.3.3 Electrical Safety

The electrical power needed to operate the ring multipoles and dipoles is distributed to the four 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. 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 contactor within the cabinet. All current carrying terminals on magnets are protected so no conductors are exposed. The larger supplies are equipped with ground fault protection circuits. In addition, the fused 1600 Amp contactor noted in section 3.2.3 has a lockable safety disconnect and the two 400 Amp fused disconnect switches shown in Fig. 1 (3.2.3) are also lockable. Also, each 480 volt power supply has a fused, lockable safety disconnect.

4.3.4 Occupational Health Hazards

Non-Ionizing Radiation

The specification for the radiofrequency power amplifier system requires that leakage levels from the system be below 1 mw/sq. cm at 5 cm from the source, which is below the standards required at our operating frequency of 211.54 MHz. Measurements will be made to confirm that these levels are indeed within specification.

Laser Hazards

Conventional laser systems may be used for alignment purposes. These systems are subject to the BNL controls described in the BNL safety manual section 2.3.1.

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).

Fringe fields of the storage ring and transport magnets are expected to be above this level in the immediate proximity, say several centimeters, of the yoke and gap fringe field region where technicians would be expected to work, but otherwise will be well below this level in the regions of the tunnel and cave occupied by casual visitors where the entire human torso could be exposed. Field measurements will be made, and any regions above 10 Gauss will be posted as dangerous to persons with pacemakers.

4.3.5 Accident Assessment for the Storage Ring System

The electron beam striking any part of the beam pipe or lead shield in the storage ring can produce high radiation levels in the form of bremsstrahlung. The protection systems described in the foregoing sections are designed to prevent personnel from exposure to these levels. For an accident to occur, the following systems or procedures must fail:

1. The trained operations personnel would have to fail to carry out the prescribed inspection procedures.
2. The dual interlocks on the entry door which automatically turn off power to the RF and XLS ring and injection line dipole magnet systems must have failed.
3. During injection into the XLS, the dual entry door interlocks must also have failed to turn off the linac RF system, the injection bending magnet power supply and to drop the XLS injection beam stop into the beam path.

As a precondition to items 2 and 3, actual entry through the XLS cave entry door can be accomplished only by:

1. Obtaining the key from the Kirk Key Unit, which can only be released if the injection magnet power supply is turned off and if the XLS and X-Ray injection beam stops are down. Accessing the key without these conditions implies the simultaneous failure of two independent shutter switches, AND the power supply off switch.
2. Mechanically breaking through a very sturdy Kirk Key deadbolt door lock.

All of the above procedures rely upon the operators carrying out an area search and clearing all personnel from the area prior to securing it. The search is enforced by the check stations which must be pressed in the proper sequence to place the interlock in the "secured" state. The backups to this procedure are the visible and audible warnings in the interlocked area and the emergency off buttons which exist in all potential radiation areas which will inhibit beam operation and revoke the interlock state.

BROOKHAVEN NATIONAL LABORATORY
MEMORANDUM

DATE: May 16, 1989
TO: NSLS Professional and Supervisory Staff
FROM: Tom Dickinson
SUBJECT: Area Safety Tours

Periodic safety tours of the Light Source are important in identifying and eliminating various hazards which occur from time to time. Other departments at BNL have had the practice of assigning staff members to go on these tours. This has proved to be valuable in educating the staff in safety issues, since the maintenance of a safe workplace depends on the actions of all those who work there. We have decided to adopt this practice at the NSLS.

The Light Source has been divided into ten areas for the purpose of conducting safety tours. Most of these require quarterly inspections, while office areas must be toured yearly. This amounts to 37 tours a year, and each staff member will be assigned to participate about once every two years. Those who are involved in this round will find a schedule attached.

The areas and their safety representatives are listed below:

VUV Experimental Floor	Richard Garrett
X-Ray Experimental Floor	Roger Klaffky
X-Ray Tunnel and Equipment Area	Roy D'Alsace
725A Technician Area 535C, 510E	Bill Cahill
Control Room, Linac, Inside VUV Ring	Norman Fewell
Buildings 726 and 727	Ed McKenna
535C and 197	Ed Gaudet
Building Exterior and Trailers	Mike Kelly
Accelerator Test Facility (Bldg. 820)	Cyrus Biscardi

CA:lf

Info Copy:

C. Auguste	S. Krinsky
K. Batchelor	P. LeDoux
T. Dickinson	H. Schulman
C. Flood	C. Weilandics
G. Kinne	

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

DATE: May 8, 1987

TO: NSLS Staff and C. Meinhold, C. Flood, C. Weilandics and
R. Zantopp, of S & EP

FROM: S. Krinsky, Deputy Chairman, NSLS JX

SUBJECT: NSLS Safety Committee

I am pleased to announce that Ken Batchelor has agreed to serve as chairman of the NSLS Safety Committee. The members of this committee are:

<u>NAME</u>	<u>BLDG</u>	<u>NAME</u>	<u>BLDG</u>
K. Batchelor (chairman)	725B	R. Larson	510E
T. Dickinson	728	T. Oversluizen	510E
N. Fewell	725B	N. Rohrig	535A
M. Kelly	535B	C. Weilandics	535A
R. Klaffky	510E	G. Williams	510E

I wish to thank all the members of this committee for their efforts to maintain proper safety standards at the NSLS.

REVISED 11-26-89

To: NSLS Operators and Operations Coordinators

From: Tom Dickinson

Subject: X-ray Tunnel Search

The x-ray tunnel is the most extensive of the high hazard radiation areas at the NSLS, and the search of this area must be done carefully by properly trained personnel. The control room operator on duty must always be aware of the status of the interlocks and in control of that status. All of this has implications for the search procedure and for the qualifications of those who carry it out.

X-RAY TUNNEL SEARCH PROCEDURE

1. Two people are required for a search. One of these must be either an operator or an operations coordinator, and the other must also be selected from the list of qualified searchers.
2. Permission for securing the x-ray tunnel must be given by the control room operator on duty.
3. The searchers should determine that all work in the tunnel has been completed, and cleanup work done. This often requires that a walk around be done before the search. Anyone in the tunnel should be asked to leave at this time.
4. The Kirk keys for "RF System Test Mode" must be in place in the x-ray security rack, and the XLS enclosure must not be interlocked.
5. The actual search must be done without interruption, such as waiting for work in the tunnel to be completed, and without extraneous tasks, such as collecting and carrying objects out of the tunnel during the search. If an interruption occurs, the search should be dumped by pressing (and then resetting) an emergency stop button, and then starting the search over when the interruption has been dealt with.
6. Step-By-Step Search Procedure

The search of the x-ray tunnel is started and completed at the two doors which separate the x-ray tunnel from the XLS enclosure. One searcher enters each door, and the doors are closed. The check stations inside the tunnel near the doors, CS-5A and CS-5B, are wired in series and must be pressed simultaneously to start the search and the six minute time limit. Pressing these buttons also illuminates the "DO NOT ENTER" signs over the doors. If either door is opened before the searchers have completed their circuit and are ready to leave, the search will be dumped and will have to be started over. One searcher turns right and proceeds around the tunnel in a clockwise direction, while the other turns left and goes counter-clockwise.

X-RAY Tunnel Search
Revised 11-26-89

The searchers must look carefully for any person who may be in the tunnel. In particular, the "sawtooth" areas must be examined using the mirrors provided and by looking around the magnets. The space between the magnets and the outer wall must also be checked. In addition, the searchers should check that all plug doors are in place, and that the shielding has not been removed from the "windows" where the beam pipes pass out of the tunnel.

If any person is encountered during the first half of the search, they should be told to move toward the entrance doors, but not to open the door since this would dump the search. (If a person is found in one of the sawtooth areas or on the back side of the magnets, the search must be dumped and restarted only after they are out.)

Each searcher presses the search button at the 90 degree point as they pass. The pilot light on each button remains on, indicating that the search relays are latching properly. The first searcher to reach the 180 degree point waits for the other searcher to arrive. One guards the tunnel while the other enters the emergency exit area, verifies that no one is there, and presses the search button.

The searchers continue around the tunnel in their original directions, and from this point on they must insist that any person encountered must move ahead of them toward the tunnel entrance. When both searchers arrive back at the entrance doors, they compare notes and verify that every person who has been seen in the tunnel is at the entrance and ready to leave.

Check stations CS-5A and CS-5B are pressed simultaneously, providing a ten-second interval during which the exit doors may be opened, and everyone leaves the tunnel. The doors are closed, CS-4 is pressed, starting the warning interval. (This button is not effective until the ten-second time-out is over, so the searchers must remain at the tunnel exit doors until the door guard is active again and the search may be completed.) The Kirk keys are removed and placed in the lock in the security rack. The searchers must remain at the security rack until the "Timeout Complete" light comes on, indicating that the warning interval has been successfully completed. The control room operator on duty must then be informed that the x-ray tunnel has been secured.

PERSONS QUALIFIED TO CONDUCT A SEARCH OF AN NSLS RADIATION AREA

NSLS Control Room Operators
NSLS Operations Coordinators
Bob Best
Tom Dickinson
Norm Fewell
John Gallagher
Richard Heese

12-20-89

To: NSLS Operators and Operations Coordinators

From: Tom Dickinson

Subject: XLS Area Search

The XLS area interlock is logically very similar to an x-ray hutch interlock, and the search procedure is similar to one of those areas.

XLS AREA SEARCH PROCEDURE

1. Verify that the x-ray ring is secured before the search of the XLS area is undertaken.
2. Obtain permission from the Control Room Operator before securing the XLS area.
3. One searcher is required. Enter the door from the power supply area, and turn right. The first check station, CS-1, is located on the right wall, near the single door into the x-ray ring. Press CS-1 to start the search.
4. Move around the XLS storage ring, verifying that no one is in the area. Press CS-2 on the wall to the right of the double door into the x-ray ring.
5. Leave the area and close the door. Press CS-E outside the door, which will start the warning interval. The total time between pressing CS-1 and CS-E may be no more than 30 seconds or the search will trip, and must be started over.
6. Lock the door Kirk lock, remove the key, and place it in the bottom SRU by the XLS interlock logic box and shutter control.

NOTE

It is possible to secure the XLS when the x-ray is not secured, but it would not be possible to inject beam. A safety problem could arise if there were someone in the x-ray ring when the XLS was secured since emergency exit would be blocked by the deadbolt Kirk lock on the XLS door. There is an emergency release of this lock from the inside, but the situation should not be set up on purpose.

PERSONS QUALIFIED TO CONDUCT A SEARCH OF THE XLS AREA

NSLS Control Room Operators
NSLS Operations Coordinators
Bob Best
Tom Dickinson
Norm Fewell
John Gallagher
Richard Heese
Wayne Rasmussen
Pooran Singh

BROOKHAVEN NATIONAL LABORATORY

M E M O R A N D U M

DATE: July 14, 1982
TO: C. Weilandics
FROM: J. Levesque *jl*
SUBJECT: XLS Control Room - Bldg. 725

This will confirm our recent discussion regarding the XLS interim Control Room.

A wood frame trailer is to be used as an interim Control Room for the XLS set-up at Bldg. 725. The trailer will be in place for two years. The trailer will be located west of the ramp leading into the NSLS Courtyard.

The computer equipment can be replaced within two months and is valued at \$80,000 to \$100,000 (figures supplied by user).

My recommendation for the appropriate level of Fire Protection is:

Since the trailer construction and placement do not comply with DOE's Standard on trailers, smoke detection and automatic sprinklers should be installed. These systems are readily available from the main facility.

JL/sc
cc: J. Deitz
f: 12
XLScont.725

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

DATE: November 21, 1989
TO: R. Church, Chief Operator, NSLS
FROM: R. Heese
SUBJECT: XLS Fill Procedures and Records

The number of fills of the XLS storage ring have been limited by the BNL Safety Committee and the NSLS Safety Coordinator to the following conditions:

1. Each fill shall take no more than 20 minutes.
2. The frequency of fills are limited to no more than one fill per hour.
3. The number of fills are limited to 200 per month.

These restrictions are due to possible radiation hazards, and may be removed after loss studies have been conducted.

Please establish the necessary record-keeping procedures to allow these conditions to be enforced.

cc: K. Batchelor
T. Dickinson
N. Fewell
J. Keane
C. Weilandics
R. Zantopp

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

DATE: November 15, 1989
TO: R. Heese
FROM: K. Batchelor *K.B.*
SUBJECT: XLS Area Radiation Studies

As a result of the radiation studies carried out on November 8, 1989
I recommend the following actions:

1. That flag #3 in the Booster to x-ray Transport Line be either removed or modified as that it can be retracted further from the beam line center.
2. That lead shielding be placed at the injection line level on the aisle side just downstream of the flag #3 location.
3. That a chipmonk radiation monitor be located in the XLS area just outside of the double entry door to the x-ray ring tunnel.
4. That until such time that the above can be accomplished work in the XLS area be carried out only when x-ray ring injection is not in progress.
5. Written operating procedures be prepared for occupying the XLS work area during x-ray injection.
6. The XLS area should be designated as a radiation area and signs to indicate this should be placed on the entry door.

The enclosed note gives a brief summary of the results of our study.

cc: R. Blumberg ✓
T. Dickinson
N. Fewell
C. Flood
N. Rohrig
C. Weilandics

Beam Loss Radiation Studies In The XLS Area

The maximum reading in the XLS area stored beam at 2.5 GeV (164mA) was 0.69 mR/HR, at the injection line level outside of the large entry door to the x-ray tunnel. A normal stored beam dump of 144.5 mA at 2.5 GeV gave a maximum level of 0.12 mR at the same location. When the stored beam at 750 MeV energy was scraped off near the XLS area the maximum level in the XLS area was 0.78 mR/HR (in a 5 minute period the stored beam current was reduced by 42 mA). If a 200 mA stored beam current had been reduced to zero in this way the total dose would have been 0.325 mR.

During "Normal Injection" the maximum level at any point in the XLS area was 28.5 mR/HR, at injection line level just outside the large entry door to the x-ray tunnel. With beam deliberately steered into the injection line near to the XLS area the maximum level recorded was 110.9 mR/HR at this same location.

During "Normal Injection" between 25% and 30% of the beam is intercepted by transport line flag #3 even though it is the "Out" position. This flag is situated at the same point in the injection line that gave maximum radiation levels in the XLS area. This flag is almost certainly responsible for the relatively high levels recorded during "Normal Injection".

2-19-90

To: NSLS Operators and Operations Coordinators

From: Tom Dickinson

Subject: Securing the XLS Area for X-Ray Injection

Radiation studies carried out on November 8, 1989 showed that there are high levels of radiation in the XLS area during injection to the x-ray ring. These levels ranged from about 30 mR/hr during normal injection to over 100 mR/hr when the injected beam was steered into the beam pipe near the XLS area. When beam was stored in the x-ray ring, levels in the XLS area were less than 1 mR/hr even when the stored beam was deliberately dumped.

Because of this, the XLS area must be closed during x-ray injection, but the area may be opened when beam is stored in the x-ray ring. The interlock system has been arranged so that the XLS area must be searched and secured in order for x-ray injection to be possible. In addition, if the XLS interlock is broken during x-ray injection by removing the XLS Kirk key from the SRU, or by forcing open the door, the linac-booster will turn off, and the injection shutter will close. A copy of the operations procedure "XLS Area Search" dated 12-20-89 is attached for reference.

This is now an additional requirement for x-ray injection. If it is not possible to open the injection shutter, the following should be checked.

1. The x-ray ring is secured, with both Kirk keys inserted and rotated in the Kirk unit on the security rack.
2. The LEGS tagging cave is closed, and the Kirk key is inserted and rotated in the SRU at X-5.
3. The XLS area is secured, with the door and lockout Kirk keys inserted and rotated in their respective SRU's.
4. The XLS shutter enable key is inserted and rotated in the key box by the control room.
5. The XLS interlock chains, XLS A and XLS B, are not tripped due to a power dip or other disturbance.

Note that items 2 through 5 will not disturb the stored beam in the x-ray ring, they only prevent injection.

BROOKHAVEN NATIONAL LABORATORY

M E M O R A N D U M

DATE: April 10, 1990

TO: R. Blumberg

FROM: K. Batchelor *K.B.*

SUBJECT: Accident Situation Whereby 750 MeV Electrons are Bent by the First XLS Transport Dipole

It is possible, though unlikely that while the Booster is being used to inject electrons into the X-Ray ring the first transport line dipole for the XLS can be energized. In this case, 750 MeV electrons will emerge from that dipole's vacuum chamber and, unless appropriate shielding is provided, strike the concrete wall of the X-Ray ring tunnel. It is unlikely that this situation would continue for a long time but we will conservatively estimate that it could continue for 20 minutes, the normal fill time for the X-Ray ring or the XLS.

The number of electrons extracted from the booster and fed down the transfer line is 10^{13} per hour at an energy of 750 MeV. This is equivalent to an electron current of 5×10^{-8} amperes. We can obtain the absorbed dose index rate D_{IO} ($\text{rads m}^2 \text{min}^{-1}$) at a reference distance of 1 meter from the source from NCRP Report #51.

This gives for the forward (0°) direction for a lead target.

$$\begin{aligned} D_{IO} &= 10^9 (\text{rads m}^2 \text{mA}^{-1} \text{min}^{-1}) \times 5 \times 10^{-5} (\text{mA}) \\ &= 5 \times 10^4 \text{ rads m}^2 \text{min}^{-1} \end{aligned}$$

We wish to stop the 750 MeV electron beam in lead and to shield the resultant γ -rays and neutrons produced so that outside of the X-Ray or XLS shielded areas there is no level greater than 5 mrem in an hour.

The stopping distance for 750 MeV electrons in lead is approximately 40 cm and γ 's are produced along the path taken by these electrons giving essentially a line source. We can use the isodose curves given in Section 5.3.2 of the National Synchrotron Light Source Safety Analysis Report, BNL 51584, to estimate the extra lead required to shield these γ -rays.

The forward direction requirement in terms of radiation length X_0 (0.56 for lead) is calculated to be 31, or a length of 18.3 cm, and the sideways distance in terms of the Moliere length X_m (1.3 cm for lead) is 3.3 or a width of 4.5 cm. We will therefore provide a lead shield of length 24" and width 8" as shown in Figure 2(1). The concrete shield wall will further reduce the X-Ray levels to a negligible value.

We can also calculate the neutron flux from the formulation given in Section 4.3.2 of the NSLS Phase I SAR as:

$$\phi = \frac{2.5 \times 10^{15} \frac{\text{MeV}}{\text{hr}} \times 2.1 \times 10^{12} \frac{\text{neut}}{\text{Kjoule}} \times 1.6 \times 10^{-16} \text{ Kjoule/MeV}}{4\pi(200 \text{ cm})^2}$$

$$= 1.67 \times 10^6 \text{ neutrons/cm}^2\text{hr}$$

where the concrete shield wall is 200 cm from the assumed source. To attain 5 mrem/hr outside the shield we have a conversion factor of 3×10^{-9} rem/cm² which from the shielding curves of NCRP Report #51, gives a value of 150 gcm⁻² or 65 cm of concrete shielding. The existing walls of the X-Ray tunnel and the XLS area provide this shielding. However, the roof of the X-Ray tunnel is only 30 cm thick. We are therefore providing an extra 12" thick concrete shield over the lead adjacent to the XLS dipole magnet to reduce the levels on the X-Ray ring tunnel which is not a normally occupied area.

BROOKHAVEN NATIONAL LABORATORY

M E M O R A N D U M

DATE: May 21, 1990

TO: K. Batchelor

FROM: C. Weilandics/R. Zantopp *C. Weilandics / RZ (info)*

SUBJECT: Additional Fault Studies Near XLS

On April 25, 1990 additional radiation measurements were made outside of the shielding, which encloses the area of X-ray and XLS injection transport systems. These measurements are intended to supplement those made on November 8, 1989. During this study the injection system was operated in three fault conditions as described below. The electron energy was 750 MeV. The Booster output current was only one third of its normal level (not by design). Therefore, the dose rates should be scaled up appropriately.

The measurement techniques were similar to those described in the report of the fault study done on November 8, 1989 (See Memo of December 18, 1989, Weilandics to Batchelor -X-Ray Ring Fault Studies Near XLS) with one minor exception. The sensitivity of the Anderson - Braun detector for these measurements was taken as 6500 counts/mrem or 0.154 urem/ct as per latest calibration. As previously, the Chipmunk sensitivity was set for 1 urad/pulse ($Q=2.5$). The data is tabulated below and a map showing the survey points is attached.

Three consecutive fault conditions were set up for this study. The first was the XLS transport line dipole, which diverts the beam from the X-ray transport line, was powered up to normal current for bending 200 MeV electrons. This configuration allowed measurements to be made to determine the dose rates in occupied areas if this dipole magnet were to be powered while attempting to fill the X-ray ring with 750 MeV electrons - a primary concern. 12 inches of lead designed to be permanently installed (temporarily installed for this study) downstream of the XLS dipole appears to be quite effective in limiting the external radiation consequences in all but the tunnel roof area. This area is not normally occupied, but certainly could be during maintenance work for instance.

The second fault condition was similar to the first, except the dipole magnet current was reduced to half its normal current. The lead backstop still intercepted the electron beam and no increase in radiation was seen on the X-ray experimental floor.

The third fault condition was a beam loss near the X-ray injection septum. Although a total beam loss in this region of the injection system is truly a fault condition, it should be noted that some beam loss is inherent in normal operations and requires a section of the X-4 experimental area to be posted as a Radiation Area.

2

Booster Pulses In Transfer Line With Conditions Below	Dose Rates (mrad/hr) At Locations Below										
	1	2	3	4	5	6	7*	8*	9	10	11*
XLS Dipole on	0.8	0.4	---	0.7	0.2	0.6	0.7	---	---	28	0.3
XLS Dipole .5 I	---	---	---	---	0.2	0.6	---	---	---	15	0.4
XLS Dipole off	---	---	13	0.8	0.1	0.4	---	0.3	16	2	0.4

* Anderson-Braun Det. (mrem/hr)

CW/sc

cc: R. Blumberg
T. Dickinson
C. Flood
S. Kramer
D. Mc Whan
N. Rohrig
f: Fault2.mem

XLS FAULT STUDY 4-25-90

MONITOR LOCATIONS ON
 EXPERIMENTAL FLOOR LEVEL AND TUNNEL ROOF

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

DATE: September 22, 1989
TO: R. Heese
FROM: R. Miltenberger *RPM*
SUBJECT: NESHAPs Review of X-Ray Lithography Source (XLS)

The XLS Safety Analysis Report section on airborne emissions indicated that XLS represented a new airborne emissions source within the National Synchrotron Light Source (NSLS). Since 1985, the Environmental Protection Agency, under authorization by the Clean Air Act and codified by 40-CFR-61 Subpart H, has the authority to approve the construction/modification of radioactive airborne emissions at DOE facilities. There is no "de minimis" level in the existing code of federal regulations. Consequently, any level of modification or addition needs to go through the regulatory process. Modifications to facilities which are considered maintenance are not regulated. Likewise, redistribution of a source within a building that does not change the airborne emissions level or the release point does not require regulatory authorization or review. The EPA airborne emissions regulations are in the process of change. On October 31, 1989, EPA is scheduled to introduce new regulations which will require DOE facilities to perform similar airborne emissions analyses but will not require their approval to initiate construction or modifications if the resultant dose is below a "de minimis" level.

The discussions that we have had since the distribution of the SAR and the Safety Committee Review have increased my understanding of the system. However, I am still concerned that XLS constitutes a new source and will need a written statement from you regarding the radioactive airborne activity generated by NSLS, the method of discharge into the environment, the impact on radioactive airborne emissions that XLS will have and the effluent release point if different from NSLS. It is imperative that this analysis be performed with the utmost candor. If a NESHAPs evaluation and/or authorization is required, we must execute whatever actions are necessary to minimize any delays the permit/technical review process will take. If, on the other hand, there is a technical justification that is professionally defensible and supports a conclusion that a NESHAPs evaluation is not required, this approach should be pursued.

I will review your written evaluation upon receipt in conjunction with N. Rohrig and W. Casey.

RPM/cjs

cc: W. Casey
J. Naidu
N. Rohrig

BROOKHAVEN NATIONAL LABORATORY

M E M O R A N D U M

DATE: September 28, 1989

TO: R. Miltenberger

FROM: Richard Heese *RH.*

SUBJECT: NESHAPs Requirements for XLS (Generation of airborne emissions)

The discussions that have occurred since the distribution of the SAR and its review have centered on the generation of airborne positron emitters ($_{7}N^{13}$ and $_{8}O^{15}$). At this point I feel that XLS will not be a new emitter of airborne isotopes, since the electrons that are injected into XLS would have been deposited into a beam dump directly from the linear accelerator after travelling through about 60 cm of air after emerging through a thin window. If these electrons are inserted into the booster and then into XLS, most of the beam power will be deposited into shielding blocks, vacuum chambers, etc. and less beam power is dumped into the air, thus generating fewer airborne emissions than generated by the beam dump.

It is my contention then, that XLS is not a new airborne emission source at NSLS.

RH:es

BROOKHAVEN NATIONAL LABORATORY

M E M O R A N D U M

DATE: October 11, 1989

TO: R. Heese

FROM: R. Miltenberger *RPM*

SUBJECT: Final Review of X-Ray Lithography Source (XLS) for Compliance with 40 CFR 61 Subpart H , NESHAPs

Upon considering the information presented in the XLS Safety Analysis Report, our conversations, your memo dated September 28 concerning generation of airborne emissions at XLS, discussions with W. R. Casey and N. Rohrig, and an NESHAPs type assessment performed by Dames and Moore consultants, I concur with your assessment that the XLS Facility does not significantly alter the source term which generates radioactive airborne emissions at the NSLS. Consequently, a 40 CFR 61 Subpart H submission to EPA for an application to construct or modify the facility is not required.

The justification for this conclusion is based primarily on two documents that you have provided: the XLS SAR and your September 28 memo. In the SAR, it is clearly stated that XLS constitutes a change in the internal configuration of the NSLS building. The space required for use by XLS is to be obtained by realigning shield walls and existing partitions. Existing building ventilation systems provide routine air changes to the space occupied by XLS. Your September 28 memo removes uncertainties concerning the source of electrons for the facility. It is apparent from this memo that the source of electrons for the XLS is the National Synchrotron Light Source (NSLS) linear accelerator. The NSLS linear accelerator generates more electrons than can be currently used by the VUV or x-ray rings. The excess capacity is presently dumped to a Faraday cup in the NSLS. This represents the source of airborne activation at the NSLS, Bldg 725. The source term generated by the NSLS linear accelerator can be highly variable and is dependent on the amount of research (i.e. beam time) available in any given year. The NSLS was constructed prior to the 40 CFR 61 Subpart H permitting requirements and thus does not have a NESHAPs application nor does it require one at this time. The XLS project extracts some of these unused electrons, accelerates them from 80 Mev to 200 Mev and then stores these electrons in a storage ring. The reaction cross sections for electrons in air between 80 and 200 MeV is believed to be nearly equivalent. Consequently, the air activation source term is essentially unchanged by the installation of XLS within the NSLS Building.

As per discussions with EPA Region II officials, memos which document the decision not to file an application are forwarded to EPA on a periodic basis for their information and review. Should they have any questions concerning the information used to develop this determination, I will need to request your assistance in providing this information.

RPM/med

cc : W. R. Casey
J. Naidu

G. Penny, DOE/BH
N. Rohrig

B. Royce