**Appendix 11**

# Radiation Hazards associated with the Laser Electron-Gamma Scattering (LEGS) Experiment at X-5 [1]

## I. Introduction

Radiological issues associated with LEGS operations at beam line X-5 (see figure 1) are sufficiently different from other beam lines at the NSLS to warrant special discussion. Three classes of radiation hazards encountered in LEGS are: synchrotron radiation, high-energy photons, and energetic electrons.

The synchrotron radiation hazards are minor compared to those associated with a NSLS bending magnet or undulator beam lines since there are no magnetic fields that the electrons are directly exposed to in traversing the X-5 straight section. There is the potential for encountering fringe magnetic fields from other beam lines that can produce synchrotron radiation in the X-5 line. Estimates of the synchrotron radiation levels inside the hutch, during normal operation, and during special alignment operations are discussed below. These hazards are readily addressed using practices common for all beam lines.

The high-energy γ-ray radiation fields produced in the X-5 beam line are due to both bremsstrahlung produced by electron-gas molecule interaction in the X-5 straight section and those produced by the laser electron gamma scattering. The LEGS beam is more highly collimated than the gas bremsstrahlung and is located completely within the bremsstrahlung core. Its energy spectrum extends to a maximum energy of ~ 530 MeV for 3.0 GeV operation (see Table below), whereas the bremsstrahlung spectrum extends to the maximum energy of the electron beam. Because of the lower energy and lower fluence of the photons produced by laser-electron scattering, the bremsstrahlung shields installed and located along the LEGS beam line as specified for all NSLS beam lines are also adequate to handle the LEGS photons. The shielding is described in greater detail, and dose estimates are made for normal and abnormal operation below.

Energy of High Energy Photons Produced by Laser Electron Scattering

| Laser in Use | Wavelength of Laser Output (A) | $E_e$ = 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 |

[1] This analysis is based on work previously included in the Phase II Safety Analysis Report dated June 1989 by Peter Stefan.

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.

Further characterization of each of these radiation hazards is given below.

## II. Synchrotron radiation

A small amount of synchrotron radiation is possible in the X-5 0° line due to circulating electrons interacting in either the fringe field of the magnet X8BM2 or the field near the edge of dipole X1BM1. Estimates of the source strength and transmission have been made for normal operation as well as scatter rates that could occur in the laser hutch These calculations predict a maximum dose during normal operation of $5.6 \times 10^{-2}$ mRads/hr in an unshielded configuration. This dose rate is insignificant and is easily shielded by the walls of the hutch.

Potential fault conditions have also been evaluated. 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. Estimates of the source strength and transmission have been made for this operation as well as scatter rates that could occur in the laser hutch. These calculations predict a maximum dose during normal operation of 1.6 rads/hr in an unshielded configuration. However, this radiation field is fully shielded by the 2" of lead on either side of the optical elements and the 1/8" steel panel walls of the laser hutch which will reduce the radiation levels outside the hutch to insignificant levels.

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 has two levels, one at 9 feet and one at 13 feet. There is one air intake in the 9-foot section that 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 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 which fully shields the synchrotron radiation fields.

## III. Gamma Radiation Hazards

The maximum photon intensity in the LEGS beam is about $3 \times 10^7$ $s^{-1}$. Behind the laser hutch, this beam has a cross section of approximately 3 cm wide x 1 cm high, and the maximum dose equivalent incurred by someone standing in this 3 $cm^2$ beam would be ~ 1000 rad/hr [2] which requires that the hutches and target cave be cleared and interlocked during operation.

There are three exclusion zones for the X-5 line, i.e. the laser hutch, the target room, and the vacuum pipe between them (see figure 2). All are interlocked in accordance with normal NSLS design practices to prevent direct exposure to the γ-ray beam. Pb bremsstrahlung shielding is provided along the beam line to prevent any ring source from exposing these zones.

The LEGS γ-ray beam can produce scattered radiation fields from interactions along the flight path. The principal scattering sources for the γ-ray beam are the collimating slits inside the laser hutch, the target within the target room and the dump at the back of the target room. There are other minor scattering sources in the laser hutch, including the quartz windows and optical lens. All scattering sources have been locally shielded as described below.

### Radiation levels in Laser Hutch

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. Nickel has been used as the primary collimator because of the low (γ, n) cross section which reduces neutron production by a factor of about four. The nickel collimator is 16 radiation lengths long, followed by 20 radiation lengths of lead.

All scattering surfaces in the laser hutch have 2" of lead on either side of them. Walls of 2” lead and 4” borated polyethylene flank the Ni slits, which may intercept a

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[2] Assumes 9.4 $p/cm^2/s$ = 1 mrem/hr (obtained from Accelerator Health Physics; Patterson and Thomas, p.59). It should be noted that the photon field is contained within a 3 $cm^2$ beam . Therefore, the effective dose equivalent rate will be a factor of 2 – 5 smaller than the calculated maximum dose equivalent rate.

substantial fraction of the beam. This shielding has reduced radiation levels outside the hutch to insignificant levels.

As the high energy photons pass down the beam line after generation , the total amount of material (e.g. quartz windows, optical lens) they encounter before the start of the low vacuum system amounts to ~ 11% of a radiation length. Electron-positron pairs that are produced by the γ-rays while passing through these materials must be removed to prevent interference in the target room and are deflected out of the γ-ray beam by a "sweeping" magnet with a magnetic field of 1.31 Tesla. The γ-rays pass from the entrance of this magnet to the target in an evacuated pipe to minimize additional pair production 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. All deflected electrons traverse a minimum of 35 radiation lengths of lead, which is surrounded by a minimum of 4" of borated polyethylene to remove neutrons. The sweeping magnet current and field strength are independently monitored and must be satisfied for the beam shutter to be open.

**Radiation levels outside transport line between laser hutch and target room**

The γ-ray transport line between the laser hutch and the target room is pad-locked and Kirk-locked in place to ensure that it is in position when the beam shutter is opened. There are other interlocks which must be satisfied as well. With the transport line in place and the vacuum established (< 0.1 torr), the two 7" (I.D.) gate values at either end of the transport line flanking the access-corridor can be opened (see fig.2).

Radiation levels in the access corridor are completely negligible under normal operating conditions with the sweeping magnet energized, normal vacuum in the pipe and the gate valves open. To ensure proper positioning of these conditions, a temperature-compensated thermocouple gauge senses the vacuum in this line and the positions of the two 7" gate valves are sensed with microswitches. The radiation levels in the vicinity of the γ-ray transport line have been calculated for fault conditions. The maximum dose against the pipe is ~ 60 mRads/hr and drops to about 10 mRad/hr at 1 foot. All sensors monitoring these conditions are interlocked to the user interlock circuit which closes the bremsstrahlung shutter if any detect an improper condition.

**Target room**

An enlarged view of the target room is shown in Fig.3. There are two nominal target locations shown in the figure. The interlocked portion of the beam pipe terminates 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. Radiation emerging from thin targets (including the primary photon beam) will be within a highly forward directed cone peaked in a few degrees about the beam direction. Essentially all of this cone will enter the shielded dump cave at the end below grade level.

Although thick targets are not normally planned, the radiation shielding for this room was designed for loss of the photon beam in a thick target prior to the dump. The highest possible radiological hazard 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 target room 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. 3) 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 target 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 target point, due to $3 \times 10^7$ photons per sec striking one radiation-length of lead at the end of the pipe, has been calculated with GEANT. Maximum dose rates are less than 0.03 mRad/hr at any point in the walkway. Calculations were also performed for the scattered radiation levels in the control room which has minimum distance of 2 meters from a potential thick target. The control is shielded by 1 foot of normal concrete which will significantly further reduce the unshielded value of 0.03 mRad/hr.

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 $3 \times l0^7$ photons per second, depositing all 500 MeV of its energy in a target, and using the conversion of 3.4 $\times 10^{-4}$ n/MeV (Swanson, Health Phys. 37 (1979) 347), a neutron source of $\sim 5 \times 10^6$ n/s will be created. These neutrons come mainly from the nuclear giant dipole resonances and average ~ 7 MeV in energy, emitted roughly isotropically. The closest point to the beam line in the inside of the computer room is 2.0 m away. Using a conversion factor of 6.8 $n\text{-}s^{-1}cm^{-2}$/mrem/hr, the dose rate at this point would be 1.5 mRem/hr. The computer room is shielded with a 1 ft. thick layer of normal-density concrete (Fig. 3). This value is a worst-case condition since LEGS operations involve thin targets, not target thick of this magnitude. In addition, the assumption that all of the energy of the photons is released as neutrons is also very conservative.

High-energy neutrons (> 100 MeV) can also be created by the high-energy photon interactions in the target. These are about a factor of 100 less intense than the giant resonance neutrons calculated above. 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 22-1/2° at the target point (the center of the small circle in Fig. 3). No radiation levels have ever been observed above the dump from LEGS operation. In addition, soil activation produced by these high energy neturons has been calculated in Appendix 11A and found to be insignificant.

**Access Control for Laser and Target Room**

The radiation interlock circuit for LEGS uses the standard captured key system, designed around KIRK locks, that are 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. 2. 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.

## IV. Tagging electron cave

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. 3). 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 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-l/2"x l9" 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. Dose rate in the electron beam is ~ 192 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.

Access to the tagging focal plane cave is prevented by procedure and interlocks when the tagging magnets are on or when 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.

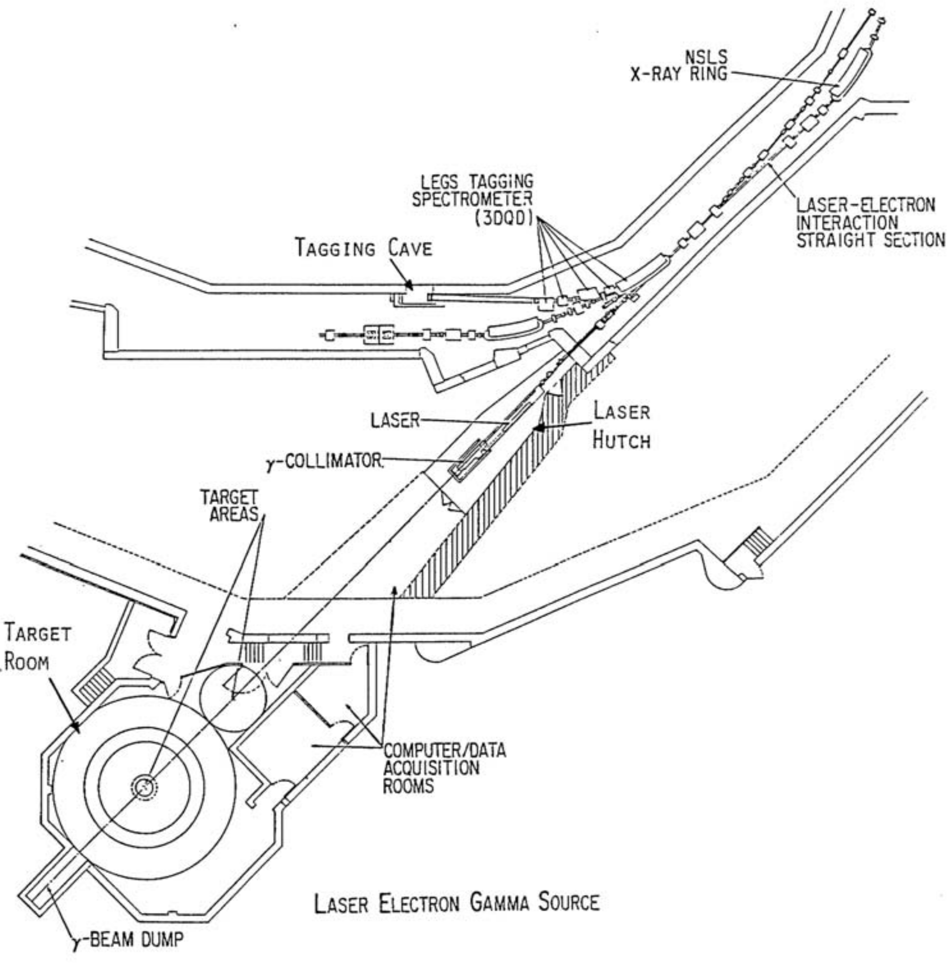


Figure 1

Laser Electron Gamma Source (LEGS) Beam line Layout

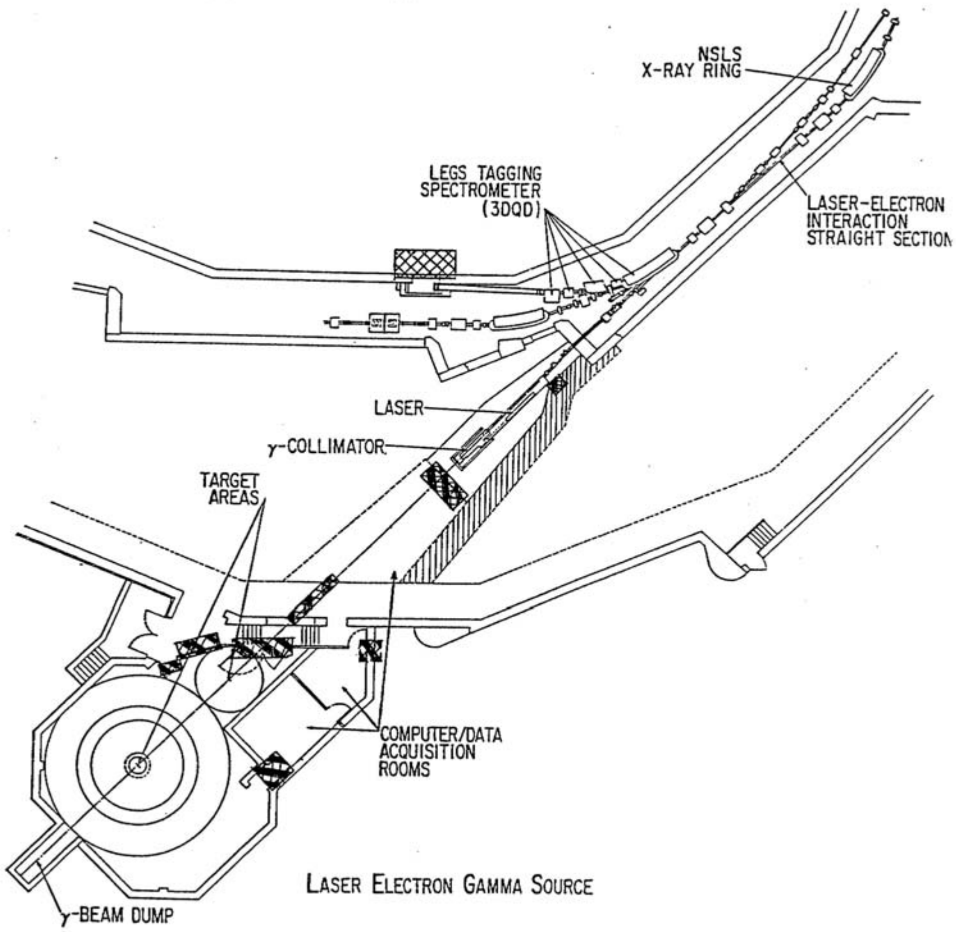


Figure 2

Interlocked Areas in LEGS Beam Line

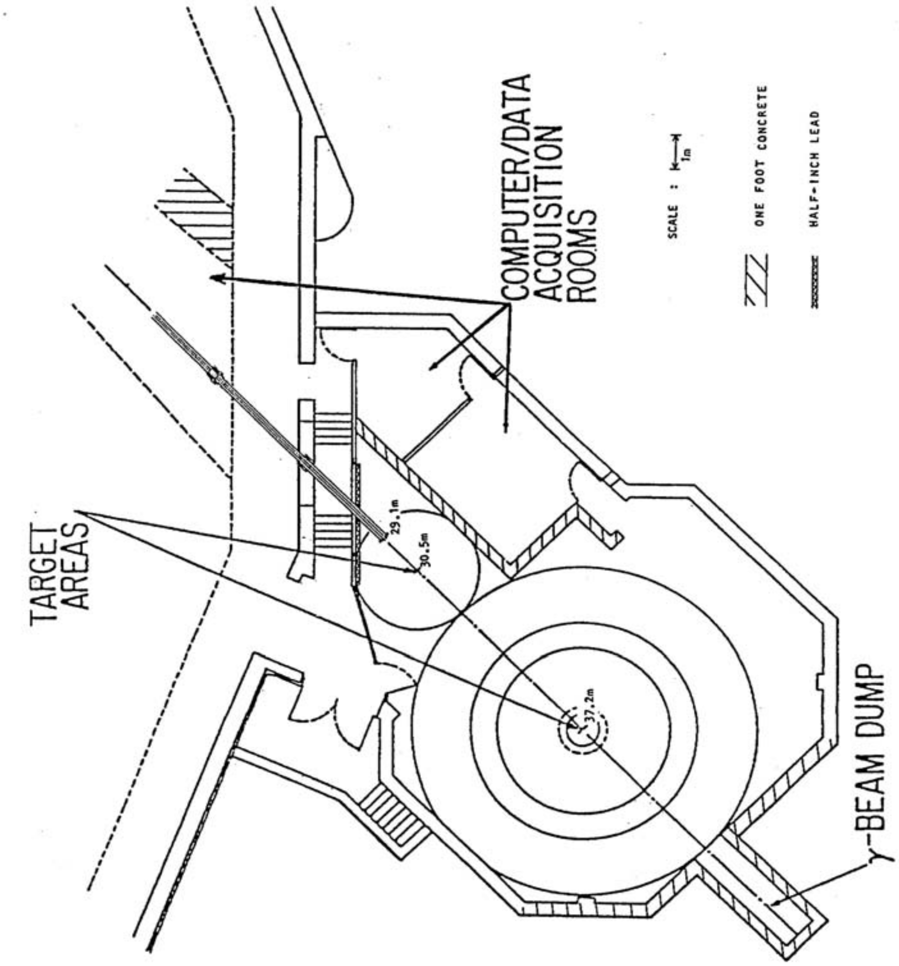


Figure 3

LEGS Target Room

Appendix 11A

**Radionuclide Production in Soil From the Operation of the X-5 Beam Line (LEGS) at NSLS**

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6/19/02

Introduction

A need for the assessment of the production of radionuclides in the soil surrounding the beam stop was identified in the development of the safety documentation for the X-5 beam line and the associated beam stop. This document evaluates the production of tritium and sodium-22 from high-energy neutron spallation in the soil.

Beam Stop Design for X-5 and Radiation Generation

The design of the beam stop for the X-5 beam line is to attenuate the high-energy photon beam (0-470 MeV) from the X-5 (LEGS – Laser Electron Gamma Source) experiment. The photon spectrum is shown in Figure 1. In the calculation the energy of the photon beam is assumed to be 300 MeV to maximize production of high-energy neutrons (see Fig. 3.8 in Ref. 7).

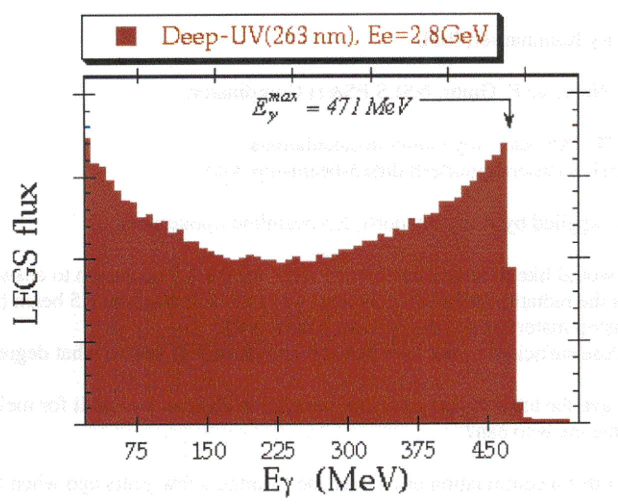


**Figure 1**

The components of the beam stop are behind a 25 cm lead glass photon monitor as shown in Figure 2. They include a nickel cylinder for photon attenuation that is 16 radiation lengths thick and a lead cylinder 20 radiation lengths thick. The nickel cylinder is used first to minimize photo-neutron production as its cross section is less than 1/4 of the photoneutron production cross section of lead, (70 mb vs. 290 mb). The beam stop is surrounded with 10 cm of polyvinyltoluene for neutron attenuation. The beam stop is 55 cm above the concrete floor and between 20-30 cm from the concrete walls.

The high energy photons are rapidly attenuated in the nickel primarily through interaction with atomic electrons and to a much smaller extent through interaction with the nucleons. Interactions with the atomic electrons are primarily through electron pair production and result in an electromagnetic cascade which produce photons of much lower average energy than that of the incident photon field. The attenuation length for 300 MeV photons in nickel is 2.25 cm. Although the electromagnetic cascade will produce some additional high energy neutrons, the production rate is much lower than that calculated below and will be ignored. Because of the large pair production cross-sections, high energy photon interactions are limited to the first few cm of the nickel.

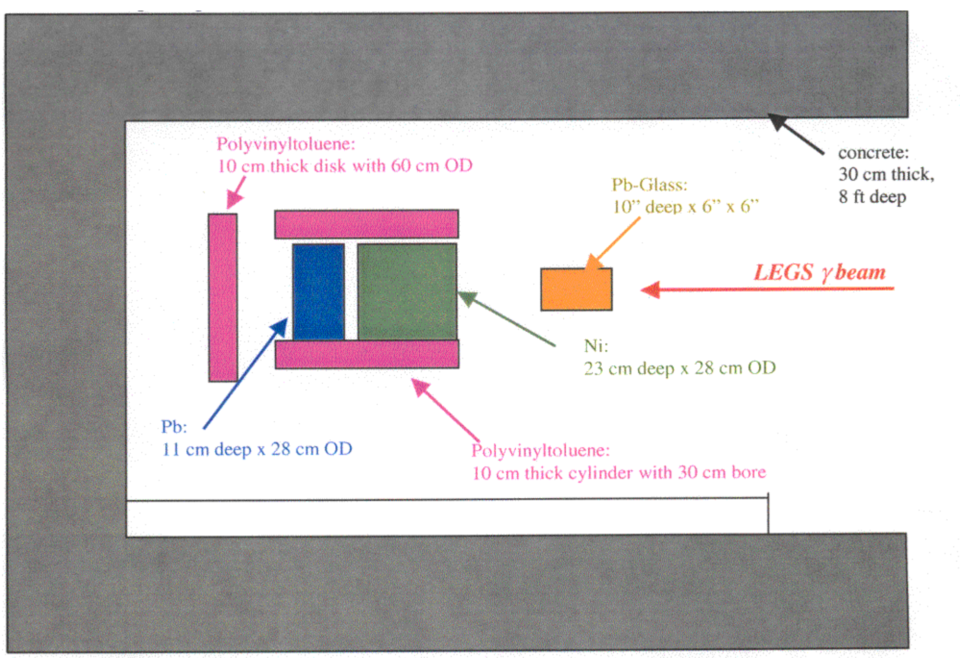


**Figure 2**

Production of Tritium from High Energy Neutrons

The high energy photon interactions in the nickel will produce neutron fields with a wide range of energies. Primarily, the neutrons are produced from the giant resonance process, which creates neutrons with an average energy of a few MeV, which therefore lack sufficient energy to produce spallation reactions in the soil molecules. Neutrons above 20 MeV can produce spallation reactions and are produced through pseudodeuteron disintegration and pion production interactions. The predominate interaction above 150 MeV is the pion production interaction; the other competing interactions are smaller by at least an order of magnitude.

The neutron yield Y can be calculated using the following expression:

$$Y = N_{atoms}\ \sigma\ \phi$$

where $\sigma$ is the cross-section for neutron production, $\phi$ is the photon fluence, and N is the number of nickel atoms subject to the 300 MeV photons. The cross section in nickel for this mode of neutron production is 29 mb, using Figure 3.8 from Reference 7. As mentioned above, the photon field is rapidly attenuated by the much higher pair production cross-sections. The total number of nickel atoms $N_{atoms}$ exposed to high energy photons is:

$N_{atoms} = 6.02 \times 10^{23}$ Atoms/g-atom / (58 g/g-atom) x 8.9 g/cm$^3$ = $9.24 \times 10^{22}$ atoms/ cm$^3$ x d (penetration depth in nickel); and d is:

$$d = \int e^{-\lambda x} dx$$

where $\lambda$ is the atomic electron attenuation length and is = 0.44 cm$^{-1}$ in nickel at 300 MeV.

Integrating this expression between 0 and infinity, we have:

$$d = 2.27 \text{ cm}$$

Assuming a 1 cm$^2$ beam, the total number of nuclear interactions can be calculated by the following expression:

$$Y = 2.27 \text{ cm} \times 1 \text{ cm}^2 (9.24 \times 10^{22} \text{ atoms/ cm}^3) (29 \times 10^{-27} \text{ cm}^2) (1 \times 10^7 \text{ n/ cm}^2\text{/s})$$

$$Y = 5.9 \times 10^4 \text{ n/s}$$

This neutron yield is primarily forward directed with an opening angle of $10^0$ (Ref. 1) . Assuming that the soil is 1 meter from the nickel, the high energy neutron fluence (HEN) at the entrance to the soil is:

$$\Phi_{HEN} = 5.9 \times 10^4 \text{ n/s} \div 976 \text{ cm}^2 = 60 \text{ n/cm}^2\text{/s}$$

In addition to the distance, there is 11 cm of lead, 10 cm of polyvinyltoluene, and 30 cm of ordinary concrete between the nickel. Each of these materials will attenuate the neutron beam as determined by its HEN attenuation length. The attenuation in each material is shown in Table I.

Table 1

HEN Shielding in Beam Stop Materials

| Material | Distance | Density | Shield thickness x | $\lambda$ | Attenuation |
|---|---|---|---|---|---|

| | (cm) | ($g/cm^3$) | ($g/cm^2$) | ($g/cm^2$) | ($e^{-x/\lambda}$) |
|---|---|---|---|---|---|
| Lead | 11 | 11.35 | 125 | 191 | 0.52 |
| Polyvinyltoluene | 10 | 1 | 10 | 70 | 0.87 |
| Concrete | 30 | 2.35 | 70.5 | 120 | 0.55 |

Therefore the fluence entering the soil is:

$$\Phi_{HEN} = 60 \text{ n/ cm}^2\text{/s } (0.52)(0.87)(0.55) = 15 \text{ n/ cm}^2\text{/s}$$

The tritium production activity A can be calculated using:

$$A = N \times \sigma \times \Phi \left(1 - e^{-\lambda t}\right)$$
$$N = atoms/g$$
$$\sigma = spallation\ cross\ section = 10\,mb$$
$$\Phi = the\ incident\ neutron\ flux$$
$$t = is\ the\ irradiation\ time = 700\ hr$$
$$\lambda = 0.056\,yr^{-1}\ for\ tritium$$

The 10 millibarn cross section for tritium production from spallation is taken from Attachment 3 in Reference 2. The number of target atoms per gram of soil ($SiO_2$) with a soil density of 1.6 $g/cm^3$ is N.

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

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

Therefore, the tritium activity production per gram of soil A for a 700 hr per year operation is:

$$A = (3 \times 10^{22} \text{ atoms/g})(10 \times 10^{-27} \text{ cm}^2)(15 \text{ n/ cm}^2\text{/s})(1 - e^{-0.056/365/24*700})$$

$$A = 2.01 \times 10^{-5} \text{ d/s/g} = 5.4 \times 10^{-4} \text{ pCi/g tritium}$$

$$A = 5.4 \times 10^{-4} \text{ pCi/g tritium} \times 1.6 \text{ g/cm}^3 = 8.7 \times 10^{-4} \text{ pCi/ cm}^3 \text{ tritium}$$

The Accelerator subject area in the SBMS provides a methodology for determining the acceptability of the induced activity in the soil. In this model, all the activity produced in one year is assumed to be located within 1 attenuation length in the soil. This amount of tritium is assumed concentrated in the soil water content (0.1 by weight) leachate and diluted by an average rainfall in a year. This concentration is assumed to be the leachate that is then compared to the action level of 5% of the drinking water standard. The model assumes an average rainfall of 55 cm/yr.

Soil water Leachate = $8.7 \times 10^{-4}$ pCi/ cm$^3$ ÷ 55 ÷ 0.1 = $1.6 \times 10^{-4}$ pCi/ cm$^3$ = 0.16 pCi/l

The SBMS subject area establishes the value of 1000 pCi/l as the action level for further safeguards and monitoring. Therefore no corrective action is required for this level of tritium production. If X5 operated at 2000 hours per year, this would yield 0.46 pCi/l; still well below the 1000 pCi/l action level.

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

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

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

$$A_{Sat.}(H^3) = 0.12 \text{ pCi/g}$$

Therefore,

$$A_{Sat.}(Na^{22}) = 6.1 \times 10^{-2} \text{ pCi/g}$$

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

$$A_{1\ yr.}(Na^{22}) = 1.4 \times 10^{-2} \text{ pCi/g or}$$

$$A_{700\ hours}(Na^{22}) = 1.3 \times 10^{-3} \text{ pCi/g}$$

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

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

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

**Conclusion**

Tritium and sodium-22 production in soil from operation of the LEGs beam line does not require any additional engineering controls or monitoring. Again, 2000 hours of operation per year would yield $8.0 \times 10^{-2}$ pCi/l; also well below the 20 pCi/l action level.

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