Easy Access Shielding Structures for the DUVFEL Beam Line at BNL's Source Development Laboratory

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Abstract

A novel method of beam line shielding has been implemented that maximizes radiation safety and allows easy access to beam line components while minimizing the stacking of lead bricks, This method can be applicable to other beam line shielding applications.

A radiation analysis established minimum shielding requirements for the Near Infra-Red Scalable Undulator System (NISUS) and the Deep Ultra Violet Free Electron Laser (DUVFEL) beam line at BNL's Source Development Laboratory (SDL). In addition to the 1.2 meter thick modular concrete walls that surround the beam line, additional shielding above and on either side of the NISUS gap was required to prevent sky shine and secondary particles from becoming a radiological hazard to personnel in the SDL building. The challenge of the shielding design was to eliminate the radiation hazard while maintaining easy access to the many beam monitors and a variety of diagnostics on the NISUS table and beam line that require hands-on manipulation. A novel approach to shielding design has been implemented around the NISUS magnet; 2,000 pounds of lead and 18,000 pounds of boronated polyethylene were incorporated. In addition, over 25,000 pounds of cast lead plates surround other areas of the beam line. Presented is the detailed design of the movable shielding. This novel approach allows a single user to gain full access to NISUS within a matter of seconds. Administrative and engineered safeguards are implemented prior to interlocking to prevent any non-compliant occurrence. This shielding system greatly simplifies the earlier method of lead-brick stacking and can be used in future beam lines to eliminate overhead sky shine problems. This method greatly simplifies and improves the immediate access to the beam line, shortening shut down periods and reducing operational costs.

Keywords: SDL, NISUS, radiological safety, shielding, easy access

1. Introduction

Radiation safety is a paramount issue associated with particle accelerator and synchrotron radiation beam lines. Radiological hazards to the public and environment surrounding an operating beam line must be eliminated or kept to a level which is negligible as compared with naturally occurring background radiation sources. Comparable safeguards must also be available to operators of accelerators and the users of beam line equipment.

The method to minimize the radiological hazard to personnel from a radiation source has traditionally been the isolation of the radiation source, by the use of shielding, distance and limiting the duration of exposure.

This concept has worked well in innumerable applications throughout the nuclear/accelerator communities. However, the use of shielding and the isolation concept itself inherently limits the access to the source. In electron beam lines where activation is not a significant risk to an operator, shielding may be removed during non-operating periods, so as to gain access to accelerator beam line components.

The traditional method of unstacking and restacking lead brick and/or concrete block has always been labor intensive and can be expensive, especially if frequent access to beam line components is necessary.

Quality assurance and safety procedures requiring that shielding be reinstalled in identical fashion adds to the time and cost of each shielding reassembly.

In an accelerator where considerable access to the beam line is necessary, these added costs may make a serious impact on operating costs.

Such was the dilemma of the Deep Ultraviolet Free Electron Laser (DUVFEL), and the associated beam line components at BNL's Source Development Laboratory (SDL). A ten meter long undulator magnet referred to as NISUS is used as a radiator section of a self amplified spontaneous emission (SASE) free electron laser. The undulators complex vacuum system and related numerous beam line diagnostic components had to be readily accessible.

2. Description of NISUS Shielding

The DUVFEL as depicted in Figure 1 is located behind an 8 ft. tall concrete shielding wall to isolate the surroundings from thermal neutrons and secondary gamma & X-ray emissions. The wall is composed of rectangular pillars of concrete weighing less than 4000 lbs. The modular blocks are steel rebar reinforced. An overhead crane is used to install and if necessary reconfigure the shielding as needed.

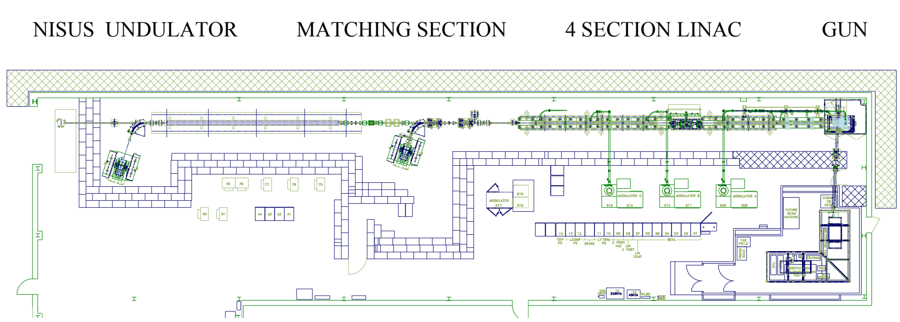

Fig. 1: SDL beam line.

Steel bars bolted onto the top of the pillars strap the individual pillars together to create a wall over 1.2 meters thick around the NISUS undulator.

A radiation safety analysis of the NISUS beam line [1] indicated that at least 2 inches of lead between the beam line and the concrete shielding wall would be necessary to reduce radiation to negligible levels. The analysis further indicated that sky shine or radiation recoiling from the roof of the building would possible increase the radiation levels in the building on the outside of the shielding wall to unacceptable levels.

The architecture of the building, the necessity of crane access, and local fire codes [2], made the option of adding a concrete roof and thereby incasing the beam line in a tunnel impractical.

The analysis indicated that at least 0.3 meters of 5% wt. boronated polyethylene would be adequate to block the thermal neutrons that emerge from NISUS.

A further complication was that the legs of NISUS magnet support table were already nearing their maximum capacity and adding the full weight of lead brick the shielding to the table could not be accommodated.

The solution to the problem is depicted in Figure 2. Plates of boronated polyethylene are strapped together with threaded steel rods forming a thick canopy over the top of the NISUS undulator. The canopy is split in two parts along the axis of the beam line. A steel post assembly surrounds NISUS. The posts are tied together with steel I-beams. I-beams are spaced equidistant to form bays along the axis of the SDL beam line. Two wheeled trucks are located between each of the I-beams. The bottom flange of each I-beam forms a track that the trucks ride on. The truck wheels are flanged

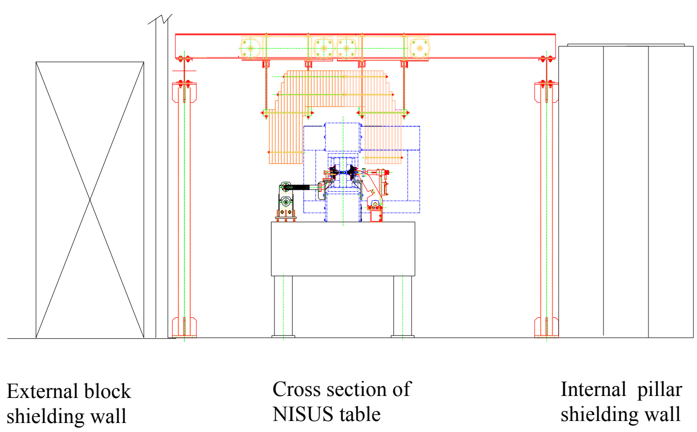

Fig. 2: Design of overhead shield canopy.

to prevent side-to-side migration of the truck during operation. Sections of the canopy each weighing approximately 900 lbs. are suspended from the trucks using lengths of threaded steel rods. In each bay two canopies composed or boronated polyethylene plates conform around the top half of the NISUS magnet assembly. Once completed the blocks are easily movable by hand to allow easy access to the wiggler magnet, its services and diagnostics. A preexisting overhead cable tray and cables supplying power to steering elements and diagnostic components of the NISUS beam line could not be moved during the installation. Slots were cut into the mating surface to allow ribbons of cables to pass through to the magnet assemble.

The height of each canopy above the NISUS table was determined as a compromise between the diagnostic components on the NISUS table and the height of the primary shielding wall. 5% by weight boronated polyethylene has double the neutron stopping power as does concrete. Fortunately, the concrete shielding wall could be located close enough to NISUS so that a line of site overlap will occur between the two types of shielding. A particle would have to traverse at least 0.3 meters of boronated polyethylene and then traverse at least 0.6 meters of concrete before exiting the shielding system and striking the roof of the SDL building. Figures 3 and 4 depicts the cross section of the NISUS magnet, and the "close-in" custom conformable lead shielding used to attenuate the gamma and x-rays prior to ejection to the surrounding boronated polyethylene or concrete walls.

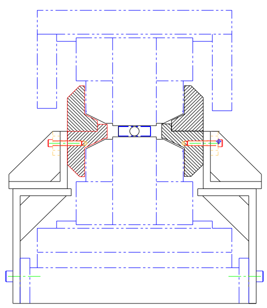

Fig. 3: Magnet gap shielding design.

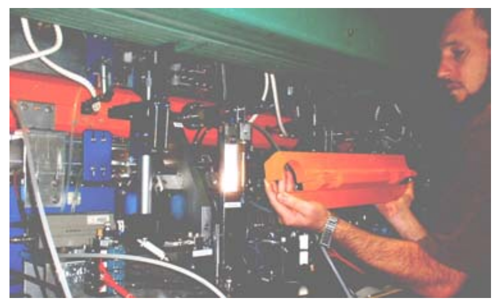

Fig. 4: Cast segment of magnet gap shield.

During operation the electron beam enters NISUS through its aluminum vacuum chamber. The beam wiggler in response to the alternating magnetic fields and spontaneous emissions of synchrotron light are produced. These emissions add together to create the coherent SASE ultraviolet beam. During normal operation minor beam halo scraping of the inside of the beam tube will cause a slightly elevated radiation level above background. The serious problem occurs when destructive beam diagnostics are introduced into the beam path. The 200 MeV beam is scattered by the diagnostic probe. The scattered electrons strike the probes components and the inside wall of the beam tube causing the ejection of gamma rays. The gammas pass into the surrounding magnet materials and attenuate by recoiling neutrons and x-rays from around the structure.

A specially designed "close in" lead shield was developed to reside in the magnet gap and conform to the magnet cross section. The design and fitting of this conformable shielding was quite challenging due to the fact that many necessary penetrations are required for electrical, vacuum, cooling water and diagnostic feed-trough's. The special shape was selected to optimize the gamma ray stopping distance within the lead and to minimize the added weight to the NISUS magnet assembly. By doing so, less than 2000 lbs. of additional lead shielding were added to the system this value could be easily accommodated by the table supports. This solution reduced by at least 1 order of magnitude the amount of lead that would be necessary if conventional lead bricking was used. The individual lengths of conformable shielding are designed so each can be manipulated into place by a single person.

3. Shielding Economics

Experience has shown that the initial price of a long term operating system is not necessarily the primary cost factor when considering a specific design. It is the overall long term cost of the system which justifies an up front investment in a more elaborate shielding system.

From experience with previous systems it can be shown that the cost to unstack lead is approximately $3/brick. An equivalent amount can be estimated for a standard concrete block. Restacking bricks can cost approximately $4/brick. For a 10-meter wiggler magnet assembly such as NISUS approximately 2000 blocks of concrete would be required to supply the equivalent amount of shielding. The minimum of $14,000 would be expended each time the magnet assembly is exposed and restacked. If the concrete blocks had to be removed more then a few times per year justifying the investment of an over hanging shielding structure might be justified. At present the easy of accessibility has already paid for itself despite the fact that no other practical method could be found to eliminate the sky shine.

4. Lead Plate Shielding

On either end of NISUS beam line diagnostic components, magnets, and a variety of vacuum hardware are all potential sources of scattered radiation. Electron beam mis-steering incidents can occur at any time during machine commissioning or tuning. Therefore the minimum of a 2-inch thick shielding requirement applies to the entire approximately 40 meters of the 200MeV beam line.

Similar access and economic concerns were raised with the beam line as were raised with the NISUS magnet. It was determined that the majority of the beam line would only need sporadic accessibility. However, the cost of the lead brick stacking was still seen as cost prohibitive. Over 10,000 bricks would be needed to stack the entire beam line. The cost of one unstuck and restack would justify a significant investment. Up front costs of at least $70,000 in labor might be saved if a modular system of lead plates could be implemented.

The decision was made to install shielding support stands along the beam line. Inexpensive aluminum weldments were fabricated to provide a substructure onto which large precise lead plates are secured. Figures 5 and 6 depict a portion of the shielding system of the SDL beam line. The cast plate shielding system provides solutions to much more vexing issues other than accessibility and stacking costs.

Lead bricks once assembled into a shielding system that is certified for operation must not be removed from that system. Therefore, special precautions must be used to prevent an individual from removing a brick thereby compromising the integrity of

Fig. 5: Closed canopy over NISUS.

Fig. 6: Cast lead enclosed beam line.

a critical safety system, metal banding or locking a metal enclosure around a shielding is often used. This adds to assembly and facility costs and further limits beam line access during down periods.

An additional safety hazard is the lead itself. With time lead oxide will form on the surface of the bricks. This oxide can contaminate personnel through physical contact or secondary contact with work gloves or overalls, or as airborne lead oxide particles. Uncoated lead bricks will in time oxidize and with ever more stringent restrictions on exposure the use of hand stackable lead is becoming a progressively less attractive method to shield beam lines. Removal of oxidized lead bricks causes a “HAZMAT” disposal problem that pushes long term operating cost even higher.

The use of large painted pre-cast shapes virtually eliminates these long term problems. Epoxy paint is used to coat and encapsulate the lead so oxidation will not form and the size of the plate is such that they can only be lifted in a controlled manor under supervision so the risk of a few bricks being taken away is eliminated and personal contact with the material and the time of exposure is minimized.

5. Summary

In this paper, novel methods of beam line shielding have been described. The SDL uses these methods to safeguard its personnel, the public and the environment from radiation hazards. Truck mounted canopies of boronated polyethylene are used to support rapid access to the DUV-FEL beam line components which has greatly enhanced the machine operations.

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7. References

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[2] J. Skaritka, BNL NSLS Final Design Review Report No. 000169 (2000).